DAVID W. WATERS

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REFLECTIONS UPON SOME NAVIGATIONAL AND HYDROGRAPHIC PROBLEMS OF THE XVth CENTURY RELATED TO THE VOYAGE OF BARTOLOMEU DIAS, 1487-88

D. W. WATERS

Introduction.

All my life I have suffered from insatiable curiosity.

How? Why? When? Where? By whom? By what? These, I think, are the basic queries with which one can play innumerable symphonies of question and answer throughout life, until the last unfinished one...

Since what passes as my rational adulthood, or, to put this beginning into historical context, since the rise of Hitler in the early '30s cast the ever lengthening shadow of his menace across Europe and beyond, I have been possessed also by the demon of scientific enquiry, the endless restless search for certainties in a world in which the only obvious constancies are change and decay.

> «Ah, what a dusty answer gets the soul
> When hot for certainties in this our life!» (1)

And yet, that same poet, George Meredith, wrote with equal conviction:

> «Around the ancient track marched, rank on rank,
> The army of unalterable law.» (2)

Poets see things, assess events, as well as feel emotions most acutely, express them most limpidly for mortals less percipient than they.

> «As we to the brutes, poets are to us.» (3)

With this belief in unalterable laws I have been fortified in my desire to decypher scientifically enigmatic historical events of crucial importance in world history such as, to give one epoch-making yet still enigmatic example, the development of ocean navigation by the Portuguese in the first half of the xvth century. Why was it made then? And why by the Portuguese?

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(1) [G. Meredith, *Modern Love*, 1.].

(2) [G. Meredith, *Lucifer in Starlight*.]

(3) [G. Meredith, *Diana of the Crossways*, xvi.]

Why was it not made earlier? By the Genoese? Or the Venetians? Or the Catalans? Whose sea captains excelled in the xivth century in what can be fairly termed the art of mathematical navigation, in stark contrast to the Portuguese shipmasters, to whom it must have seemed a black art.

And there is another enigma. Why was it Portuguese hydrographers who, at the earliest, in the last two decades of the xvth century developed oceanic hydrography? Why was it not Genoese? Or Venetian? Or Catalan hydrographers? Up to these end of the xvth century it was they who excelled in the making of sea charts (4).

Together these two developments in nautical science and hydrography changed the face of the known world with dramatic suddenness at the end of the century and with it the balance of world power for centuries to come.

There are physical patterns of wind, weather, sea state and current — «unalterable laws» — that dictated how, when and where sailing ships traversed the oceans, as a consequence there are repetitive patterns concealed in historical maritime events. Once provide a rational basis from which to extrapolate forward then probable consequences of actions planned and executed rationally upon them. Thus, for example, there are patterns in maritime warfare that recur over the centuries technological developments notwithstanding (5).

There are other recurrent patterns in history, such as in the history of the exploration of the sea, of the oceans conspicuously, which enable us to expain rationally the course and causes of events which are otherwise enigmatic.

My reflections in this paper embody some of my later researches into the history of Portuguese navigation and hydrography but, far more importantly, the researches of historians whom I regard in our discipline as the intellectual giants of the present — Luís Albuquerque, our President, W. G. L. Randles, Eric Axelson, Charles Verlinden, Wilcomb Washbourn, Cor Koeman, Captain Max Guedes, G. Schilder, Helen Wallis, Carlo Cipolla, Lynn White Jnr., Michel Mollat and C. V. Scammell — and of the recent past — Commandant Desiré Gernez who, soon after the war first encouraged me to study the history of navigation, Eva G. R. Taylor, Peter Skelton who first introduced me to the international world of learning of maritime history twenty-eight years ago, here, in Portugal, at Lisbon, at the International Congress marking the death of Prince Henry the Navigator, where I met other intellectual giants, Joseph Needham, the late Armando Cortesão, Admiral Luis Teixeira da Mota and Marcel Destombes and, as a result, in due course C. R. Boxer, Monique de la Roncière, the late G. R. Crone and Ernst Crone of the Netherlands and J. H. Parry, and became indebted to an earlier generation of scholars whom I never met, Joaquim Bensaude, L. Pereira da Silva, Admiral Coutinho, Commandante A. Fontoura da Costa, amongst the pioneers of what I regard as the Renaissance of maritime history, in whose revealing light we now bask and upon the gathered fruits of whose learning we now so richly feed.

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(4) [The signed chart by Pedro Reinel ascribed to 1483, by A. Cortesão, *History of Portuguese Cartography* (Coimbra, 1971). Vol. I. 207-11 & Fig. 88. No earlier chart by a Portuguese hydrographer is known though it is certain that charts were constructed by the Portuguese at least forty years earlier, see C. Verlinden, *Quand commença la cartographie portugaise*? (Lisboa, 1979), separata da *Revista da Universidade de Coimbra*, Vol. XXVII, Ano 1979, 135-39, where he discusses the order of 22 October, 1443, byt he Regent Dom Pedro, concerning the making of charts — «carta de marear», printed in A. J. Dinis, *Monumenta Henricina*, I, VIII (1443-1445) (Coimbra, 1967), p. 107.].

(5) [D. W. Waters, «Seamen, Scientists, Historians and Strategy», *Brit. Jour. for the Hist. of Science*, vol. 13 No. 45, 1980, 189-210.]

But I have also discovered that other historians of a like mind to mine, but also stocked with infinitely greater knowledge and talent, have perceived in history other significant recurrent patterns on a world scale. I acknowledge in particular the vision, lucidity and eloquence of the late Ferdinand Braudel, whom I had the honour to meet, for many years also a prisoner of war.

In short, altough my theme is, broadly, Portuguese maritime history in world history I can lay claim to little personal original research into the history of Portuguese navigation, hydrography and nautical achievements in the XVth and early XVIth centuries.

In being honest I do not wish to dull the reader's sense of expectancy. I wish to give credit where credit is due.

What I can attempt as an original contribution is to present some of my own thoughts on the origins and significance of Portuguese navigational inventions and achievements in the Age of the Renaissance, roughly 1400--1600 A.D., in the perspective of world history.

Upon the cultural and artistic Renaissance of Europe humanist historians have written words as multitudinous as the sands of the sea shore and lauched books innumerable written with an ocean of ink, but have largely ignored or discounted the contributions to Western civilisation's cultural heritage made concurrently by the nautical scientists, hydrographers, shipbuilders and seamen of Western Europe, not least of Portugal. For it was largely their revolutionary activities in the XVth century that generated the wealth that made the humanistic Renaissance of that century possible, as it was the extension of their activities world wide in the XVIth century which so enriched the patrons of art and so stimulated mathematics, astronomy and the observation of natural phenomena that the best educated Europeans experienced an intellectual revolution, a revolution which, in the XVIIth century, became the Scientific Revolution.

In short, I consider that the contributions of nautical science and hydrography to Western culture in the Renaissance have been much neglected by historians.

That said I shall concern myself here chiefly with the very beginnings in the Renaissance of the revolutions that occurred in nautical science and hydrography that changed the course of world history more drastically than it had ever been changed before. In doing so I shall attempt to paint in words, but more in the manner of the 'impressionist' artists of the xixth century than in that of the miniaturists of the xvth, my picture of the most significant — most revolutionary — developments in world history in the xvth and — even more sketchily — in the xvith centuries. Unfairly, some may think, I shall leave, bequeath is perhaps the better word, the detailed infilling which will give academic substance to my arguments to the rising generation, if any should think the legacy worth the effort to take up, for, as Andrew Marvell wrote, «To his Coy Mistress», three centuries and more ago:

> «Had we but world anough, and time,
> This coyness, Lady, were no crime...
> But at my back I always hear
> Time's wingèd chariot hurrying near...»

and now, as I write, I hear it almost at my heels...

I have used the words «my picture of» and «most significant» developments in world history advisedly because there are many patterns evolving at any given time and which is or was the most important in subsequent world history is — or should be — a matter of judgment and can, therefore, be challenged. My attempt to paint in words the patterns that I see so that you can see them my way too is not intended to provoke dissent, but should be seen as an attempt to satisfy momentarily an insatiable personal curiosity, an unquenchable thirst to make order out of chaos, to make of man's history more than Macbeth's

> «...tale
> Told by an idiot, full of sound and fury,
> Signifying nothing.»

My Theme: Ocean Navigation.

Although I regard Carlo Cipolla's *Guns & Sails* as one of the great illuminating books of history for the masterly way in which he relates technological nautical detail to the synoptic narrative of European expansion 1400-1700 I have always felt he did not appreciate the fundamental importance of — or, most probably, wisely avoided the ambiguities of — the techniques of oceanic navigation developed by the Portuguese in that formative xvth century (6).

I was therefore delighted to read in Ferrand Braudel's magesterial *Civilization & Capitalism 15th-18th Century* [*sic*], first published in 1979, that, from the depths of his profound knowledge of world history, he drew the long deliberated conclusion that:

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(6) [C. M. Cipolla, *Guns & Sails in the Eearly Phase of European Expansion 1400-1700* (London, 1965).]

«Ocean navigation was the key to the seven seas of the world» (7); and that he based this conclusion upon the fact that, under the heading:

«*The triumph of the West: ocean navigation*»

«The conquest of the high seas gave Europe a world supremacy that lasted for centuries.»

He continued, for he had previously been discussing the 'symetrical' effects universally of the concurrent technological invention of printing in the mid-xvth century:

«This time technology — ocean navigation — did create 'asymmetry', an advantage on a world scale...» — for the Europeans (8).

«Ocean navigation» was an advantage on a world scale for the nations of Europe because they alone amongst the maritime nations of the world practised it. Hence the 'asymmetrical' effects upon world history of the invention of «ocean navigation».

What follows is my attempt to explain, on the basis of seamanship and documentary evidence, which includes sea charts, how I think the revolutionary art and science of ocean navigation was developed by the Portuguese in that most difficult of centuries in European history, the xvth.

The core of the problem that led to the art has never been better put than by Martin Cortes, writing in the middle of the xvith century; it was, he said, a question of how «to bryng them into the way that wander» in the ocean «where only water and heaven may be seene.» (9)

The Mediterranean pilot had had, since the xiith century, the magnetic compass with which to establish direction — North, South, East and West — when at sea out of sight of land and under overcast skies and, since the xiiith century the sandglass with which to measure the passage of equal intervals of time and so distance sailed out of sight of land. If he wished to venture out into the ocean sea it was so vast and apparently boundless that he needed an aid with which to measure his position in the sea when out of sight of land. Without such an aid he could not venture to sail any great distance into the ocean sea because, without it, he could not be certain of returning to recognisable land, or an island, before he was so lost that he and his crew perished for lack of food and water; in the Mediterranean he was never more than a day or two's sailing from land.

To devise such an aid, and the methods to use it efficiently, was the great — the greatest — intellectual and technological challenge of xvth century Europe. It was the greatest because it was «the key to the seven seas of the world» which «gave Europe a world supremacy that lasted centuries.»

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(7) [F. Braudel, *Civilization & Capitalism 15th — 18th Century*. Volume I *The Structures of Everyday Life* (London, 1985) 412; first published in France, 1979 and in England, 1981.]

(8) [*Ibid.*, 402.]

(9) [M. Cortes, tr. R. Eden, *The Arte of Nauigation* (London, 1561) fol. iii *verso*; it was first published in Castillian in Zaragoza, 1551, though written in 1545.]

The navigational aid first developed, by the Portuguese, to enable a pilot to find his position in the ocean sea was 'altitude navigation' or, as it is often called, «equal altitude navigation». It was an astronomical measuring aid.

The sea-compass used the force of *magnetic attraction* to *indicate direction*, and a *compass card* of 360 * to *measure direction;*

the sandglass used the force of *gravity* to indicate the *passage of time*, and two glass bulbs to measure the *duration of time;*

altitude navigation used the *sphericity* and *rotation* of the *earth* (apparent rotation of the fixed stars') to *indicate position* and to *measure change of position* (in North-South directions only).

In tracing the so far unexplained development of 'altitude navigation' I shall use documentary evidence of academic rectitude but also as not less reliable the intimate relationships between the visibility of and the apparent movement of the stars, the prevailing wind and current systems of the North Atlantic ocean, and the sailing capabilities of xvth century sailing ships although, for the latter, there is no documentation of the sort insisted upon by academic scholars; but the first mentioned are substantiated by the sciences of astronomy, meteorology and oceanography, the last by innumerable records of the typical performance of sailing ships «on the wind» world wide from the xvth century up to the xixth; in short, I shall use copious quantitative physical evidence to supplement and to take place of documentary evidence lacking. In other words, I shall treat the evidence of soud seamanship as being as reliable as documentary evidence on the well-attested fact that the sea suffers none to survive who disobeys its unalterable laws.

Pre-ocean navigation Europe, c. 1400.

If we look at the world pictured by the most highly educated Europeans around the year 1400 AD — these would be some ecclesiastical scholars who were advisers to the most powerful rulers of a small number of states, and larger numbers of Venetian, Genoese, Florentine, Aragonese, South German and Hanseatic merchants — they probably saw it much as delineated in the 'Catalan Atlas', perhaps by Abraham Cresques, twenty-five years previously, for presentation by King Peter III of Aragon to King Charles V of France and first found in the library of the thirteen-year-old King Charles VI of France in 1380 (10).

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(10) [It is now in the Bibliothèque nationale, Paris; it is reproduced in L. Bagrow, ed., R. A. Skelton, *History of Cartography* (London, 1964) Pls. XXXVII-XL; the authorship has been challenged bb T. Campbell, Review of *Mappamundi...*, *Imago Mundi*, Vol. 33, 1981, 116.]

This map represents recognisably to the modern eye on four panels the Southern shores of the Baltic, the British Isles, the coasts of Europe from Denmark Southwards to the Strait of Gibraltar, the NW coast of Africa to below Cape Bojador (lat. 26* N.) on the coast of Morocco, the Mediterranean and Black seas.

To the West of Portugal and of NW Africa islands are shewn in the Atlantic — the Beneventurades (the Azores) being the Northern group, the Fortunades (Fortunate) islands are the Southern group — the Canaries, above which the islands of the Madeiras are named (11).

Eastwards of the Levant, on four further panels, is a feast of symbolic flags, cities, monarchs, camel caravans, Chinese junks and a far sea shore fringed with islands, from which can be unraveled the trade routes to Cathay followed by the European merchants of the XIIIth and XIVth centuries, such as the Polos.

To my mind it is significant that the easily recognisable parts of this, the very latest and most authoritative representation of the world, are those derived from the charts of European Mediterranean seamen, Genoese, Venetian and Catalan, and from those in use in the Indian Ocean. They portray visibly the importance of the sea and seamen in history.

In 1400 European seamen traded in their ships not only throughout the Mediterranean but from its Eastern end Northwards and Eastwards into and around the Black Sea and from its western end Southwards to Safi (lat. 32* 25′ N.), Northwards and again Eastwards into the English Channel and beyond to Sluys, the port of Bruges in the Netherlands, and to the port of London. Bruges was the Southern seamens' limit.

Beyond Bruges the merchants of the predominantly German Hanseatic League dominated the trades of the North Sea and Baltic. They brought to Bruges in their cogs, which they piloted with magnetic compass, sounding lead and line only the iron, the grain, the timber, tar and pitch, hempen rope and the furs and the salted herrings and cod of the northern lands and seas. From Bruges the single-square-sailed Hanseatic cogs carried into the Baltic ports — Copenhagen, Lubeck, Stralsund, Dantzig, Konigsberg, Memel, Riga, Reval, Narva and Stockholm — the pepper and other spices of the Orient shipped from the Mediterranean, and the silks and rugs and fine cloth that made life tolerable for the wealthy merchants in the towns and the landowners in their fortresses on their vast forested estates. These lay at the limits of and formed the latest territories of what I see as the internal colonisation of western Europe, which was still recovering from the depopulation caused by the Black Death fifty years earlier.

From Bruges also the Mediterranean and the Hanseatic merchants shipped the woollen cloths woven in England and the Low Countries (where they were dyed and finished) that clad rich and poor, merchant, prince and peasant throughout much of Europe and in Mediterranean and Levantine lands.

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(11) [G. Coutinho, ed. Moura Braz, *A Nautica Dos Descobrimentos*. Vol. I (Lisboa, 1951) 163-195, «A escola do mar largo Atlântico e Costa de Africa».]

From the salt pans of Portugal and Biscayan France the Hanse shipped Northwards vast cargoes of salt to English fishing ports and, especially, to the ports of Holland and Zeeland fringing the Zuider Zee — the South Sea — the ports of the herring fishermen — Amsterdam, Udam, Sardam, Hoorn, Enkhuisen, Harlingen. From these strategically situated bases the Dutch sallied forth in fleets to catch cod and, since the recent shift of herring from the western Baltic, herring during their annual migration from the Orkneys down the Western shores of the North Sea.

The Dutch gutted, salted and packed their catch in airtight casks at sea then shipped it North, South and inland to meet the insatiable appetite of townsmen for essential protein otherwise lacking, quite apart from satisfying their appetites on the 166 fast days in the year when meat could not be eaten.

Off the Algarve the Portuguese caught and salted the tunny for markets within the Mediterranean.

Thus the abstruse doctrines of Mother Church contributed to the prosperity of maritime communities.

From London and Southampton, as well as from Bruges were shipped in the great two-masted galleys of Venice and the singleand two-masted square sailed Genoese carracks the wool that was woven into the fine Florentine and other cloths so-sought-after by the rich in every country from the Baltic to the Black Sea.

In the Mediterranean, from the Levant was shipped, by the Genoese especially, in great bulk cargoes the alum needed by the cloth weavers of England and Flanders in their processes of manufacture.

From Venice the galleys carried to Bruges the small bulk, high value cargoes of coveted spices and silks already imported by galley from the Levant.

Within the Mediterranean Venice controlled the salt-marshes of the Adriatic and Cyprus, supplying the cities of the Po valley, the inhabitants of the Alpine mountains and of southern Germany, Croatia and Hungary and added to her spice-begotten wealth with this staple trade.

Salt is not only an essential food for animals and mankind, it provided also until the XIXth century, apart from dessication by smoking or sun-drying, the sole means of preserving food in an edible state for any length of time. To span the lean months of winter, when lack of fodder necessitated the slaughter of livestock in order to feed a residue until the spring, the salting down of the carcases was — like that of fish — literally a matter of life or death.

But the human palate demands variety, if 'variety is the spice of life', as I believe it is, then spice — better still, spices — gave the XVth — and earlier — European man and woman who could afford it the variety to insipid food that their palates demanded. Certainly the spice trade in all its variety of drugs, silks, sugars, savoury and fragrant spices was in full swing by the xiith century, and amongst the so much in demand spices pepper held pride of place.

Pepper came by way of Egypt and the Levant from the Far East, from India and Indonesia. It was another main source of the wealth of the Venetian Republic, the richest state in Europe in 1400. Pepper was the Republic's 'very milk and nourishment', as it was declared in a crisis. Yet the volume was tiny by modern standards — 300 tons in a year. But the profits from its sale 'had an enormous influence upon the medieval economy' (12).

There were other lucrative cargoes carried in the Mediterranean — slaves, Moslem-owned black slaves stowed in Venetian ships and shipped Eastwards from North Africa to the Levant, and white slaves shipped from the shores of the Black Sea and the Aegean Westwards: girls to be servants and concubines of the Christian rich from Sicily to Malaga, from Bari to Venice, and to be *odalisques* in the harems of the Levant, Egypt, North Africa, and boys, and eunuchs, and youths to labour in the fields or to become soldiers in Egypt to fight for the Faith.

In this cruel trade the Genoese had become supreme since the mid--xiiith century drawing upon an endless supply of ruthlessly exploitable human beings through their Black Sea ports especially, Tana and Caffa. Through them passed Circassians, Bulgarians, Russians, Georgians and Tartars, their colours, ages, sex and other attributes carefully recorded, each priced according to his or her desirability or suitability to satisfy the varied needs of the slave dealers (13).

It was a cruel, callous and violent age. Men, subject to the blind and, as yet, unpredictable destructive fury of the elements were themselves violent, callous and cruel in response. The technological inventiveness of the West which, with the blessing of the Roman Church, was already easing the grinding physical effort of working for survival, had not had time, was not yet sufficiently wide-spread, nor diversified to humanise the lives of the bulk of those who laboured in the fields, at sea down the mines, in the workshops, and in the counting houses (14). Technological inventions humanised them by giving them the leisure, besides the time to rest from the daily fight for survival, which humanises life. For leisure gives time in which to think beyond the problems of providing the physical necessities of living, and in which to afford to act with compassion innocent of self-interest. As yet only the Church offered such leisure — but extorted repayment with celibacy, ascetism, bigotry, so slavery of the heathen and others outside the Church still flourished in Christendom.

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(12) [G. V. Scammel, *The World Encompassed The First European maritime empires c. 800-1650* (London, 1981) 101.]

(13) [*Ibid.*, 106-08, 162, 174-75.]

(14) [See Lynn White, Jr., *Medieval Religion and Technology Collected Essays* (Berkeley, Los Angeles, London, 1978) especially «The Iconography of *Temperantia* and the Virtuousness of Technology», 181-204, and «Cultural Climates and Technological Advance in the Middle Ages», 217-253.]

To compensate for this impious trade Venetian ships specialised in the transportation each year of pilgrims in their hundreds to the Holy Land, in confortable coasting galleys or more spartan great ships which made the passage from Venice to Jaffa or Alexandria direct. (15)

It was this rich and varied traffic by sea that, by 1400, had made Venice supreme in Europe, was soon to enrich Florence.

To support it Venice had an empire of islands and city ports linking her to the Levant and Black Sea. All trade to and from the *terraferma*, all exports from her islands in the Levant and her Adriatic ports, had to pass through the port of Venice wherever bound. Two hundred and fifty years later the English would similarly funnel all their colonial trade into and out of the ports of England and would rise rapidly to be supreme in the expanded European world.

So there was a Mediterranean East-West economic axis. Venice was the Western hub.

There was also a European North-South economic axis.

This extended Northwards from Venice, not only by ship through the Strait of Gibraltar but also by packhorse through the Alpine passes and Germany and Burgundy, to Bruges.

Bruges was its Northern hub, Venice its Southern hub. Bruges was also the Western hub of a Hanseatic or Baltic axis. For, in Northern Europe there was also an economic East-West axis. It extended from Bruges East into the Hanseatic Baltic, whose ports there formed the Eastern hub as Bruges formed the Western hub. Bruges was thus as predominant in the North as was Venice in the South. Together they made the North-South economic axis the critical European one.

But, despite the importance of Bruges, in 1400 the North-South European axis was unequally balanced. Venice predominated. This was because Venice was the Western hub, not only of the Mediterranean economic East-West axis, as was Bruges of the Northern East-West axis, but because Venice was in fact the Western hub of a far longer and richer East-West axis than most men imagined.

Venice was not the Western hub of a Mediterranean economic East-West axis with the Eeastern hub (which she shared with her neighbour and rival Genoa) somewhere between Constantinople in the North and Alexandria in the South (the foci of the slave and spice trades) she was the Western hub of a Euro-Asian East-West axis which extended to the farthest bounds of China and the China Seas, no one knew how far distant these islands lay.

Venice's Eastern economic hub lay thousands, not hundreds of miles to the East. From the Levant an Oriental axis stretched across the Indian

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(15) [G. V. Scammel, *op. cit.*, 109].

Ocean, far beyond the Indian peninsula, because this itself was the hub of an economic Far Eastern axis extending as far again East into the East Indies. Here lay the ultimate Eastern hub, in the Tropics, at the farthest limit of the Afro-Eurasian world, in the Spice Islands shewn on the edge of the Catalan atlas of 1375.

But the centre of gravity of this Far Eastern axis lay, like its Western counterpart, in a port, Malacca, midway between India and the Indies.

Malacca commanded the Strait between the Indian Ocean and the China Seas, whence came the cassia and cloves (grown in the Moluccas), amber and sandalwood, nutmeg and mace (from the Banda islands), white and black pepper (grown also in South India) — the fruits of *piper nigrum* — the mainstay of Venetian wealth. Whoever commanded Malacca controlled a chief source of Europe's wealth, the spice trade.

Much of this was rumoured, little for certain known (16).

What was certain was that «Balance of payments, for all European merchants in the spice trade, was a more serious problem than either restrictions of supply or governmental squeeze», applied at numerous points of control along this sinuous, seemingly endless spice route, both of which perennial problems increased by the throttling Turkish conquests in Asia Minor and the cupidity of Mameluk Egypt (17).

But the metals that made up the essential specie, gold, silver and copper, were in increasingly short supply from the European mines — in Germany, the Tyrol, Carinthia, Transylvania and Bohemia. As a consequence the Venetian and Genoese trades with North African ports, in timber, ships, wine, glass beads, copper and cloth were of particular importance, not merely as an additional source of slaves but as a source of supply of the specie most in demand, gold.

The Venetians and Genoese were paid for the cargoes which they sold in the ports of Barbary in part in gold, which goes far to explain why, despite their religious enmity, they traded with the Infidel. They did not know the source of the gold only that it had been carried northwards across the vast Sahara Desert by caravans of camels and slaves, who bore also ivory and ebony and coarse but pungent *malagueta* pepper.

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(16) (G. R. Crone, in his though provoking «Some Reflections on the History of Discovery and Exploration», *Revista da Faculdade de Ciencias*, vol. XXXIX (Coimbra, 1967) 115-20, after reminding the reader that when, in the 1250s, the Franciscan «William of [Rubruquis reached the Great Khan's court [in Karakorum], he found numerous European merchants, jewellers, clock makers and others...», from whom no written accounts of their travels and activities have come down, but who inevitably knew much about what Crone called an Asian «economic circulation system». And he reflected that, «Before the Portuguese era in the East there were doubtless many merchants and other travellers who succeeded in penetrating into this trade orbit [«an established» Indian Ocean «economic circulatory system»], though few of their names have come down to us.» But the fact that some have implies that they returned to recount some of their knowledge of the East though, not being travellers «intent to discover and reveal a new part of the *orbis terrarum*» what they said, in place of writing, became hearsay about the Orient, with the lack of precision that that too implies, but was grist to the geographers' mill.]

(17) [J. H. Parry, *The Discovery of the Sea* (London, 1981, 76-7.]

This pepper had been grown in the forest belt of Guinea, even farther to the South than where the Maghribi merchants traded their goods in the cities of the great middle bend of the Niger River. Gao. Timbuktu, Jenne, Niani, for gold.

All that was — and is — known of the source of this gold was that it came from regions likewise farther South. It had been brought thence to the edge of the forest zone and exchanged there by anonymous dumb barter for that indispensable nutrient, salt, salt which had already been carried South to the Niger marts, in the first stage of the trade, by camel caravan from rock salt deposits in the Sahara around Ouadane, Tagazza and Bilma, then by headload to the forest edge (18).

Portugal, Lisbon and European seaborne trade, XIVth c..

The conquest by the Portuguese of the Algarve from the Moors was completed by the capture of Tavira in 1238. With the siege and capture of the great port of Seville by Castille in 1248 the conquest of Andalusia was also completed. Thus, after 1248 only Granada remained under Muslim rule in Iberia, but by paying a large tribute to Castille. Passage through the Strait of Gibraltar now became reasonably secure for Christian merchant shipping with ambitions of trading outside the Mediterranean.

The capture of the Algarve had not severed its trading ties with North Africa merely changed the traders. Because by this time the Genoese had developed their trade with the ports of North Africa, not only South of Genoa but also out through the Strait of Gibraltar to the ports on the Atlantic coast of Morocco as far South as Safi, they were the seamen to whom the Portuguese turned most naturally for navigational expertise as their seaborne trade began to increase at the close of the century, just as it was to Genoese merchants that they turned for financial backing.

Lisbon had profited by Genoese, Venetian and Catalan ships extending, in the last quarter of the XIIIth century, their trading activities outside the Mediterranean North to ports on the Bay of Biscay and within the Narrow Seas. The splendid port of Lisbon had become, as a result, an indispensible port of call (for Seville, thirty miles up the Guadalquivir, was too inaccessible) during the long and dangerous voyages to and from the North — it was virtually the only easily accessible harbour on the whole Atlantic coast. As a further result it now inevitably became an international exchange mart. Nor is it surprising that a university was first founded in Portugal there, in 1290.

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(18) [*Ibid.*.]

In 1291, the year in which Acre, the last Christian stronghold in the Holy Lands, fell to the Infidels, two Genoese — the Vivaldi brothers — sailed from Genoa in two galleys to reach the Indies by way of the «Ocean Sea». They were not heard of again. The venture was premature, it was the era of the Tartar peace — the next year Marco Polo returned to Venice from Cathay primed with the marvels of the technologically advanced Far East and to recount them to incredulous readers.

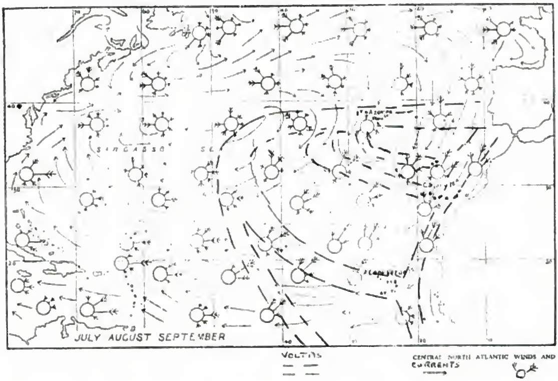

FIG. 1 — Central North Atlantic Winds and Currents, July, August, September, based on The Admiralty Pilot, and the deduced *volta do mar largo*, *volta da Guinea* and *volta da Mina*.

In Portugal King Dinis (1261-1325) understanding the importance of the sea enrolled in 1317 the Genoese Emanuel Pessagno in his service as his admiral *(meu almirante)* with twenty masters and pilots. The Genoese influence in Portuguese sea affairs was firmly established. By 1336 the Canary Islands, known vaguely since Classical times, had been re-discovered for the Portuguese (but they ultimately became Spanish — Treaty of Toledo, 1480) and in 1339 the Genoese hydrographer, Angelino Dulcert, drew on a portulan chart for the first time islands in the Atlantic — «six of the Madeira and Canary islands». The Portuguese had begun to explore the Ocean Sea (19).

With the victory of Aljubarrota in 1385 over its threatening neighbour Castille, Portugal was to become free of threats to its land frontiers but it was plagued with a shortage of gold — no gold coins were struck in Portugal between 1385 and 1435. (20).

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(19) [A. Cortesão, *History of Portuguese Hydrography*, Vol. II (Coimbra, 1971) 70-1.]

The country was poor in other ways, its population bareley one million, its two largest cities, both ports, tiny — 40,000 inhabitants in Lisbon, 8,000 in Oporto, other towns scarcely more than villages, its trade small, the land itself widely unproductive — corn had often to be brought in by sea to feed the townspeople.

Portuguese trade was seaborne, mostly in small native sailing craft but extended to the Narrow Seas as well as into the Mediterranean and along the Moroccan coast, from whose ports came mostly such gold as was earned. With the somewhat Quixotic capture of Ceuta in 1415 the Portuguese had a foothold in Africa.

Hitherto peninsular Portugal had been torn, as it were, by the pull between her two sea frontiers; the pull of the Atlantic coast with its trade, especially in sea salt from the Lisbon region, to the North, and the pull to the South of its virtually Mediterranean coast, exerted despite its few, shallow and dangerous ports, the coast of the Algarve. Now the pull was inexorably South.

But the pull was as much religous — towards conquest in Morocco, contact with Prester John to outflank the Infidels in a still Crusading age — as it was commercial, to gain gold; above all it was also intellectual in what was becoming an inquisitive age; perhaps decisively it was also meteorological, in a sailing ship age the wind system favoured voyages to the South and, if a ship were to return, necessitated sailing to the West.

This was a consequence of the technological limitations of the sailing ship, whether latteen — or square — rigged, on this latter point let there be no doubt, for with either rig she could make no headway against a wind, at best she could progress through the water at right angles to it, which she did best under a lateen sail. It will be of the greatest interest to see how the modern caravel *Bartolomeu Dias* under the command of Captain Emilio Carlos de Sousa sails (21).

Portugal lies at the Eastern focus of an eliptical clockwise wind system which covers the North Atlantic. Its longitudinal axis lies W. by S. from the coast of Portugal, where the winds are Northerly, so that the Western focus is off the coast of Florida, where the winds are Southerly. Off North Africa N.N. Ely winds carrying ships to the South prevail; off North America Westerly. Along this axis between the N.N. Easterlies and the Westerlies a broad belt of winds circulate around an inner area of variable winds manifested by the Gulf weed of the Sargasso Sea especially.

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(20) [C. R. Boxer, *The Portuguese Seaborne Empire* (London, 1969) 5.]

(21) [He is to depart Lisbon 8 November this year to repeat the famous voyage of 1487-88. The caravel has been built at the Vila do Conde shipyard north of Porto where ships are still built in the traditional way. *The Times*, 31/8/87.

Thus only as a ship sails West from the North African coast do the N.N. Easterly winds give place to variables. At first some Easterly winds will be met. These will enable her to make progress Northwards, the Southerly winds help her to progress Eastwards as well as Northwards until, in the region of the Azores, Westerly winds carry her homewards.

So wind and sail systems combined to ensure that the farther a ship sailed South from Cape St Vincent the farther she had to sail West into the ocean in order to sail North then East to return to Portugal.

This is one of those patterns of history — which no longer applies strictly to ships' movements because ships are power driven — to know which makes sailing ships' activities intelligible and made them predictable.

But why did Portuguese ships sail South after the capture of Ceuta?

This question is much debated. Ships' crews do not sail down barren and dangerous coasts and into unknown seas, nor do merchants dispatch them to do so, without expectation of reward. So this is where I see the religious, the chivalric and the intellectual pulls to the South motivating the Portuguese pioneers in the Atlantic.

However, while the Portuguese landowning and governing classes were second to none in Europe in the violence of their hatred of the Moslems and in their delight in warfare and a belated chivalry, which together had contributed most to their seizure of Ceuta, it was the personalities — the unpredictable in history — of two of the sons of King John, Pedro and Henry, which were the decisive factors in the motivation of the Portuguese Atlantic pioneers.

Portugal and the Italian Renaissance.

In 1406 the city-state of Florence had conquered Pisa and gained the port of Porto Pisano. Hitherto landlocked and reliant upon the Genoese to ship the bulk of their goods the Florentines plunged at once and successfully into the business of shipowning. Within five years a Florentine carrack was England bound (22).

I always use this as a coat-peg on which to hang the beginning of the Renaissance, for it seems to have manifested itself in Florence first unambiguously and manifestly in the person and works of that marvellous architect Filipo Brunelleschi, who designed «the first entirely Renaissance building in Europe [is] the Ospedale degli Innocenti (the Foundling Hospital), Florence, begun in 1419» and the masterly and innovatory octagonal dome of the Duomo a year later.

But another, not I think more important though perhaps better known reason for choosing 1406 as my Renaissance coat-peg is that 1406 was the year in which Jacobus Angelus or Giacomo d'Angelo da Scarperia (d. *post* 1410) completed the translation from Greek into Latin of the long-lost *Geography* of Ptolemy (c. 90-168), and that he did this in Florence for a Florentine patron of letters, Palla degli Strozzi (1370-1462).

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(22) [A. A. Ruddock, *Italian Merchants and shipping in Southampton 1270-1600*, (Southampton, 1951) 57.]

The importance of this epoch-marking work, to which was given the title *Cosmographia*, is that, unlike medieval land maps and, indeed, charts, it was based scientifically upon astronomy, the fundamental science in cartography and hydrography, as well as upon the language of science, mathematics.

It was thanks to Strozzi that the Byzantine humanist Manuel Chrysoloras (d. 1415) went to Venice and Florence where he taught Greek and «was one of the founders of Greek humanism in the west». Angelus was one of his disciples.

It was a Florentine artist, Francesco Lapaccino who delineated from the Greek codex the maps accompanying the Latin translation and another Florentine, Domenico di Lionardo, who translated the text and nomenclature of the Greek maps into Latin. Many copies of the manuscript were made, forty-eight survive, and in 1475 it was to be printed (in Vicenza) without maps, and two years later (in Bologna) with maps. Before the end of the century three more editions were published in Italy — in Rome, 1478, Florence, 1482 and again Rome, 1490, and two in Germany — 1482 and 1486 — both in Ulm. Then followed a pause of sixteen years while the lineaments of the world's face, as a result initially of the discoveries of the Portuguese seaman, Bartholomew Dias, were re-assessed (24).

I think the most striking cartographic features of the Ptolemaic maps are the mathematical projections designed to represent mathematically correctly the curved surface of the world on a fat or plane surface. But I thinfl the most important feature for hydrography is the actual network of parallels of latitude and meridians of longitude. Of the text the table of katitudes and longitudes — of some 8,000 locations — mostly based on travellers' distances, was probably to prove in concept most useful to seamen.

It was into this humanist Florentine world of geographical learning set in a mercantile and by now maritime city that, ten years after the capture of Ceuta, Dom Pedro of Portugal entered.

He had already been graciously received in England by the King and in the greatest maritime power in the known world, Venice, by the Seignory. Here he received amongst other gifts a manuscript of Marco Polo's journeyings and, importantly, a large map of the world.

Via Pavia he had passed on to Rome being received by the Pope as a notable conqueror of the Infidel.

In Florence Dom Pedro received not only financial support for placing that city on equal trading terms in Portugal with Venice but met the leading

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(23) [T. W. West, *A History of Architecture in Italy* (London, 1968) 99-100.]

(24) [A. Cortesão, *op. cit.*, Vol. I, 92-4.]

scholar-geographer Paolo Toscanelli and the chronicler of the tales of traveller merchants to the Orient, the Florentine humanist Poggio Bracciolini.

Dom Pedro returned to Portugal in 1428, 'much given to study' yet a man of action, a true Renaissance prince, geographically and commercially aware, to be Regent of Portugal for ten years from 1438 and to be killed in battle in 1449 (25).

It is unfortunate that we know less about Dom Pedro than about the Infante — Prince Henry, the so-called Navigator — because while he undoubtedly supported his younger brother in his Atlantic ventures it seems to me that it was he who kept the Infante on course, as it were, in his Atlantic enterprises in the critical early years.

Prince Henry was an ascetic, far more medieval in mind than his brother, repeatedly diverted into disastrous, costly forays against the Moors in Morocco, yet blessed with a horoscope which not only bound him «to engage in great and noble conquests» but, «above all... to attempt the discovery of things which are hidden from other men.» So he, too, was a Renaissance man with an enquiring mind.

Fortunately, Gomes Eanes de Zurara, the Infante's chronicler, gives an -- the only — example of his curiosity to find out «hidden things»; this was his 'desire to discover what lay along the African coast beyond the limits of known navigation; beyond the channel which separates the Canary Islands from the coast... to open new trades'.

Less romantically one of the sea captains Prince Henry employed, Diogo Gomes, stated simply: 'the prince wished to find the countries whence came the gold which reached Morocco by desert routes' (26). A very prudent thing to do for anyone bent upon expensive enterprises by sea.

The great triumph of both princes was to exploit the chivalric virtues of their turbulent, ambitious young warrior captains in the realisation of their own fundamentally commercial aims. The princes disciplined their captains to undertake the initially financially unrewarding and highly dangerous and arduous first exploratory voyages, but they also rewarded them with money and honours and, later, as islands were discovered with land: for these voyages were not only made but succeeded. No merchant would have undertaken these pioneer voyages into the unknown. The proof of this is that none since the Vivaldis had attempted to do so. This is what I mean by the unpredictable factor in history, personality, being such a crucial factor in the Portuguese story of their discovery of the oceans.

Of course, precautions were taken to have discoveries made properly recorded, and from this we can deduce the navigational aids provided by Prince Henry to enable his sea captains to return with an account of their discoveries and, hopefully, trade goods and gold.

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(25) [G. R. Crone, *The Discovery of America*, London, 1969) 41-2.]

(26) [J. H. Parry, *op. cit.*, 91-2.]

The oceanic discoveries of the XIVth century.

In tracing the development of ocean navigation it is important to consider the series of unsuccessful attempts made in the xivth century to settle in the already inhabited Canaries, following their re-discovery in 1336. These inevitably involved oceanic voyaging in order to return to the North and, as inevitably, sooner or later led to the discovery of other islands in the ocean, as is borne out by the hydrographic evidence of increasing numbers of islands being shewn on sea charts and portulan based maps as the century progressed. Thus the chart of 1339 by the Genoese Angelino Dulcert gives «the first positive cartographical representation [evidence] of any other Atlantic islands [than the British Isles] with part of the Canaries Group» including named islands (27). And «one of ...the traditional Fortunate islands, was by the cartographer called Island of Lanzarotto Malocello, with the cross of Genoa drawn on it» (28). He shewed three of the Madeira group as well as three of the Canaries. «...four more of the Canaries and for the first time one of the Azores, *Insula de bracir* (Terceira) is shewn in the Pizigani chart of 1367; eight of the Azores, four of them nameless, and one more of the Canaries *(talegranza)* in the Medici Atlas of *c.* 1370; and twenty-one altogether in the Cresques map of 1375» (29). As Armando Cortesão commented, «This could only have been the result of successive voyages, chiefly to the Canaries but possibly also to the newly discovered islands in the west» (30). But the diversity of the charted positions of the latter make deliberate voyages to them less likely.

That ocean voyages to the West from the Canaries were made is certain, they had to be in order to return to the North. It is true that it is possible for small sailing craft to work their way Northwards up the African coast by taking advantage of the diurnal land and sea breezes experienced close to the coast. But the labour involved in repeatedly shifting the sail or sails, in particular lateen sails, from one side to the other in order to make the series of boards necessary to zig-zag up the coast, and the frequent anchoring involved to await the breezes, makes it impracticable over long distances for vessels of any size such as must have been used on these invasion expeditions involving voyages of over 700 nautical miles (Lisbon-Las Palmas 712').

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(27) [A. Cortesão, *The Nautical Chart of 1424* (Coimbra, 1954) 46.]

(28) [A. Cortesão, *op. cit. supra* n. 4, 72.]

(29) [*Ibid.*, 74.]

(30) [*Ibid.;* in this he disagrees, as do I, with Gago Coutinho's opinion that «they were the fancy of unscrupulous cartographers.» One of the characteristics, invoilable principles of sea charts is that they shew and from the earliest shewed only known coasts and islands in what is/was believed by the discoverer/surveyor to be their true position to enable other seamen to find them. In this they differ from many maps of the Renaissance — and later.]

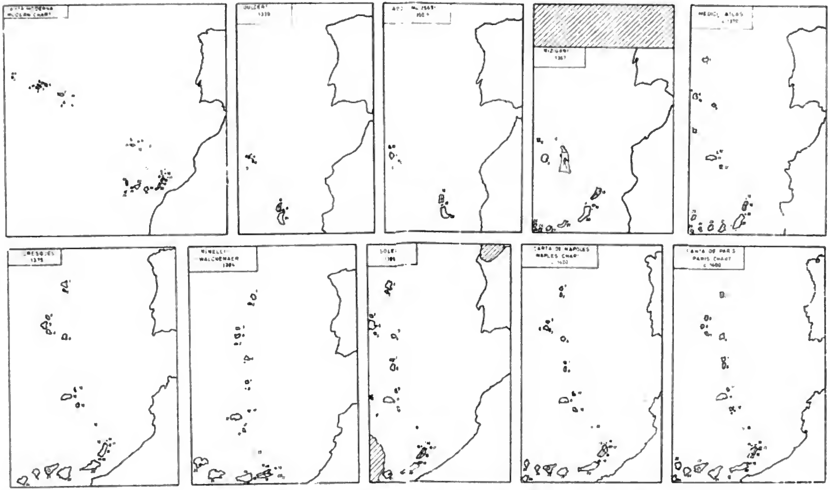

FIG. 2 — Outlines of the Atlantic Islands in XIVth century hydrography and to-day.

From A. Cortesão, *History of Cartography*, Vol. II (Coimbra 1971) Fig. 70, where the islands are numbered and identified in an accompanying table.

Their various positions of the islands reflect the diversity of their estimated positions resulting from pilots navigating in the ocean without means to check either their East-West or their North-South positions by astronomical measurement, that is, before 'altitude' navigation.

Besides the hydrographic evidence of ocean voyages as far South as the Canaries and thence to the West in the xivth century there is written evidence. Florentine merchants in Seville reported to Boccaccio (1313--1375) a Portuguese expedition of 1341 and he says that nineteen islands had been discovered. He gives a trustworthy description of the Canaries — ten islands, the remaining islands are unidentified but could be the Madeiras and six of the Azores. Another Portuguese expedition followed in 1342; two Majorcan expeditions, of 1352 and 1360 are recorded and no less than five Spanish ones between 1369 and 1393 (31).

In 1402 a settlement in the Canaries had at last been made successfully, but by a Norman, Jean de Béttencourt, under a grant from the King of Castille.

The Portuguese oceanic discoveries of the XVth century.

Prince Henry, after his return in 1418 from a relief expedition to Ceuta, seems to have started his interest in the sea. Perhaps as early as 1420 he was sending out ships and Madeira and Porto Santo were re-discovered, so confidently that they were at once settled (32). Porto Santo was settled first, amongst the pioneers being an Italian naturalised in Portugal, Bartolomeo Perestrelo, destined to be the father-in-law of another Italian adventurer, called Christopher Columbus. At about this time — 1420-1427 — Prince Henry «sent to Majorca for Master Jacome, a skilled maker of charts» — son of Abraham Cresques, perhaps maker of the Catalan atlas of 1375 — «and ... brought him to these realms, where he taught his skill to men who in turn taught men who are alive to this present day», recorded Duarte Pacheco Pereira in his *Esmeraldo de Situ Orbis* of 1505-08.

As the Catalans were the leading chartmakers at this time Prince Henry showed good judgment and an understanding of the fundamental task of exploration, to record discoveries in such a way that they can be repeated and identified by other men.

According to Commandant Fontoura da Costa Master Jacome was: «homem sábio na arte da navegação, fazendo cartas e instrumentos, para ensinar a sua ciencia aos pilotos portugueses.» (33) He was therefore doubly valuable for he was able to teach the art of navigation and would know its shortcomings for oceanic navigation.

In 1424 and again in 1427 the Infante sent expeditionary forces to capture Grand Canary from the native Guanches, presumably to set up an advance base, but each was beaten off.

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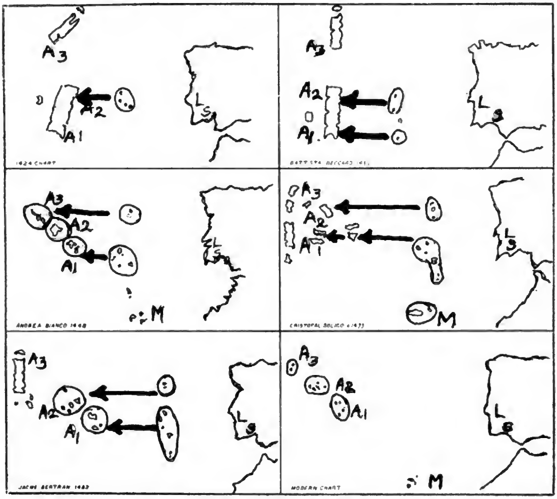
(31) [A. Cortesão, *op. cit. supra*, n. 27, 47.]

(32) [J. H. Parry, *op. cit.*, 91-2.]

(33) [A. Fontoura da Costa, *A Marinharia dos Descobrimentos* (Lisboa, 1939) 10. Unfortunately he does not cite the source of his quotation.]



— THE WESTERN COAST OF THE IBERIAN PENINSULA, THE AZORES AND THE ANTILIA GROUP IN SOME EARLY MAPS SHOWING THE TWO GROUPS OF ISLANDS DISTINCTLY SEPARATED AT FIRST AND THEN BECOMING GRADUALLY MORE CONFUSED BEFORE COLUMBUS' DISCOVERY OF AMERICA

FIG. 3 — The Azores and Madeiras in xvth century hydrography.

Adapted from A. Cortesão, *The Nautical Chart of 1424.* (Coimbra, 1954) Fig. on p. 87.

The chart reflect the improved positions in 'altitude' of the islands resulting from the use of 'altitude' navigation. They also reflect the 'double charting' of islands through continued inability to measure positions East-West, and the resultant conflicting positions of islands in longitude.

The latter was a consequence of pilots having no means whereby they could check their estimated East-West positions by measurement (in contrast to their North-South positions, which they could do approximately by 'altitude' observations). Cortesão did not appreciate that islands were 'double charted' in longitude as a result. He argued that the Western islands were the West Indian Antilles. In fact, Corvo and Flores (A^{1}) believed not to have been discovered until the 1450s appear to be shown close to their actual positions in the charts of 1424, 1435 and 1448, as well as of *c.* 1475 and 1482.

The island groups A1 (S. Maria, S. Miguel), A^{1} (Terceira, Pico, Faial, S. Jorge, Graciosa) & A^{1} (Flores, Corvo) are the South-eastern, Central and North-western groups of the Azores. L = Lisbon; M = the Madeiras; S = Sagres.

The arrows suggest the double charting in longitude of the various groups.

However, perhaps in returning on the unavoidable Westwards sweep from the Canaries or Madeiras, in 1427 islands in the Azores, perhaps all seven of the Easternmost, were positively rediscovered by «Diogo de Silves a Pilot of the King of Portugal», as a chart of 1439 by the Majorcan Gabriel de Valseca states. It is the first to show the islands unambiguously, of which

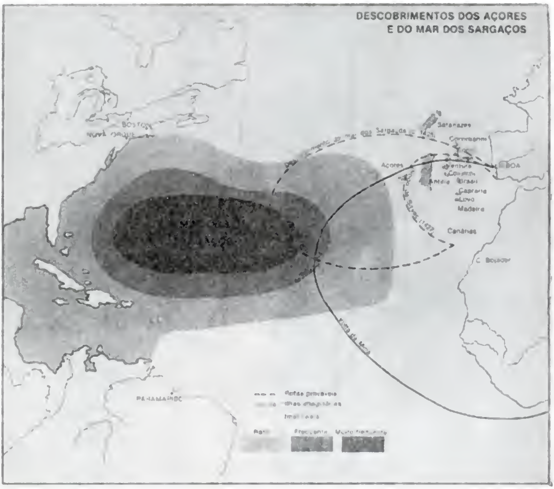


FIG. 4 — The discovery and re-discovery of the Azores in the XIVth and XVth centuries, of the Sargasso sea *c.* 1425 and the re-discovery of the Azores in 1427.

From L. M. de Albuquerque, *O Descobrimentos Portugueses* (Lisboa, 1985), Fig. 70.

The Sargasso sea is named — *mar de baga* — on a chart in Andrea Bianco's atlas of 1436.

The «Ilhas imaginárias» include, in my opinion, navigationally mis-placed Azorean islands, sometimes 'double charted' in error. 'Double charting' occurred a century and more later because of pilots' inability to measure longitude.

from Santa Maria, the most Southerly, you can see S. Miguel on a clear day. Corvo and Flores, a hundred miles to the Northwest of Fayal, and so forming the Northwestern group, were re-discovered in the 1450s, by which time the other islands had long been settled. In 1439, the Infante had granted charters for the settlement of the islands, of which he enjoyed the Lordship, as he had of the Madeiras since 1433. Here, taking shrewd advantage of the growing European demand for sugar (one of the so-sort--after spices from the East) he had canes planted successfully, as in Madeira. They were already growing profitably in the Algarve, where they had been introduced by Genoese (34).

It had been in the year following the grant of the Madeiras to the Infante that, one of his sea captains, Gil Eannes, had returned to Portugal having rounded in a single-square-sailed *barcha* the hitherto impassable Cape Bojador 120' South of Grand Canary. Two years later gold was being brought back from the socalled Rio de Ouro (River of Gold). Then, because of Moroccan involvments, for five years no expeditions were sent out.

With Dom Pedro becoming Regent in 1441 exploration was resumed and, for the first time with the more capacious and weatherly caravel. And the first slaves were captured, miserable forerunners of a trade which will make possible the cultivation of islands and continents as yet undiscovered. But exploration had begun to pay.

By 1444 the Senegal River in latitude 16° N. and the fertile land of the Blacks had been discovered. A year later the island of Arguim (South of Cape Blanco in latitude 21° N.) had been fortified as a trading post and traders began to move in, trade with the Infidels was approved as a Crown monopoly.

The next year, 1446, the Gambia River was reached, but the natives resisted exploration and the remnants of the crew brought the caravel back, piloted by a young apprentice after a voyage of two months at sea.

By 1448 over fifty ships had passed Cape Bojador and returned with trade goods and gold (35).

The discoveries were duly charted by order of the Infante and in Venice Andrea Bianco included them as far as Cape Roxo in a chart of that year, the earliest surviving cartographic record of the Portuguese discoveries south of Cape Bojador (36).

Charles Verlinden has argued: «Il n'y a absolument aucune raison de croire qu'il y ai eut des cartes portugaises avant celles mentionnées dans le diplome de 1443 [du 22 octobre 1443 de l'Infant Don Pedro, régent du royaume de Portugal]». He argues that the chart which the Portuguese «montrèrent au concile de Basle en 1435 pour prouver que les Canaries étaient plus voisines du Portugal que de la Castille... n'a rien de commun avec les cartes cotières dont il vient d'etre question. Il s'agit, sans aucun doute, d'une des cartes d'ensemble italiennes ou catalanes alors en circulation, par exemple celles du type Virga ou Mecià de Viladestes.» (37).

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(34) [J. H. Parry, *The Age of Reconnaissance* (London, 1963) 147-48.]

(35) [J. H. Parry, *The Discovery of the Sea*, 104.]

(36) [A. Cortesão, *op. cit.*, Vol. II, Fig. 76, pp. 143-45.]

(37) [C. Verlinden, *Quand commença la cartographie portugaise*? (Lisboa, 1979) 6; Separata da *Revista da Universidade de Coimbra*. Vol. XXVII, Ano 1979, pág. 135-139.]

Although he agrees that Portuguese charts «ont été établies grace aux enseignements de Jafuda Cresques...» he concludes that before 1443 «il n'y eut que des roteiros oraux...» (38).

But this ignores the fact that by 1424 Azorean islands are being charted recognisably in their approximate latitudes, and that their positions are sufficiently well established for them to be settled in the 1430s by the Portuguese. This presupposes the means to navigate to them unfailingly and such means included charts for to find such islands infallibly by «roteiros oraux» alone was not and is not practicable. The previous century's charts, on which the islands discovered were evidently plotted from «roteiros oraux», bear out this fact, which is substantiated by these island discoveries being unexploited, because unexploitable with the inadequate navigational means available for infallible oceanic island navigation, the pre-requisite to pre-planned island settlement. In other words, the Portuguese ocean pioneers of the 1420s and 1430s must have had charts of one sort or another on which to record sufficiently reliably to which islandor islands they had been to enable them to go there again by intent and not by accident.

There was now a second pause in exploration, the costs, dynastic problems (Afonso V, the 'African', succeeded in 1448), the death of Dom Pedro in 1449 and the quarrel with Castile over rights in the Canary Islands conspired to divert funds and energies, though trade continued.

However, by the time of Prince Henry's death in 1460 the scene had again changed. In part this had been a consequence of the Fall of Constantinople to the Turks in 1453 which certainly increased the difficulties in the Levant of the spice trade.

As early as 1443 the Papacy had attempted to rally Christian support against this threat but the chief fruits of the Council of Florence had been detailed knowledge of the spice trade in the Orient. The chief informant was a Venetian merchant, Nicolo di Conti, whose report of 1444 after twenty-five years of travel as far as India and China was taken down by Bracciolini and excited the interest of Toscanelli and others interested in cosmography. This was incorporated in an anonymous «Genoese» world map of 1457, now in the Biblioteca Nazionale Centrale, Florence, which delineates — for the first time — two 'spice' and 'clove' islands in the extreme South-east, evidently the Molucca Islands, and an open seaway around Africa (39).

By then, in January, 1455, Prince Henry had obtained a Bull, *Pontifex Romanus,* recognising Portugal's sovereignty to the discoveries extending from Cape Bojador and Cape Não through all Guinea and passing beyond to the southern parts and threatening with excommunication all those unlicensed by the King or Prince Henry, who entered, navigated or traded within those parts (40).

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(38) [*Ibid.,* 7.]

(39) [L. Bagrow, ed. R. A. Skelton, *History of Cartography* (London, 1964) Plate D, 72, & G. R. Crone, *The Discovery of America* (London, 1969) 42-3.]

This, no doubt, explains why, in Venice, Fra Mauro of Murano, assisted by Andrea Bianco, was receiving payments from 1457 to 1459 from the King Afonso V of Portugal for a great circular world map, which was delivered to him on 24 March, 1459. Though now lost a copy survives in the Biblioteca Marciano Nazionale, Venice. Besides its even more detailed notes on the Spice Islands it carries unequivocal inscriptions with supporting statements that «the Indian Sea is an ocean, not a lake», and Africa is delineated surrounded by sea, except where Sinai meets Egypt. (41).

So it is not surprising that in 1459 Toscanelli in Florence was talking to Portuguese envoys about the route to the Indies and showing them another world map but with which he postulated a route West from Lisbon.

But the Portuguese, whose caravels had now reached Sierra Leone in latitude 9* N., had sighted the Cape Verde Islands (which they soon colonised and planted with sugar) and were bringing back gold enough to have struck the first *cruzados* in 1457, were not persuaded. Indeed, with the death of the Infante in 1460, exploration ceased, perhaps also because navigational difficulties would increase as the Pole star sank from view above the horizon. Exploration was not to be resumed until nine years later. Even then, there is no evidence that the object was to reach India, let alone 'the Indies' when King Afonso V in 1469 leased most of the enterprise to Fernão Gomes. He paid an annual rent and undertook to explore one hundred leagues of coast annually for five years.

This Gomes did with great success. By 1471 his ships had pressed South-eastwards down the dangerous Guinea coast, rounded Cape Palmas and passed Cape Three Points sailing now Eastwards past the at last readily approachable sandy shores of the Gold Coast, the *Mina do Ouro*, whose alluvial gold from the Volta River region was a new source of supply — just as Benin, at what proved to be the end of a Gulf — of Guinea, was a new and inexhaustible supply of slaves captured in the constant tribal wars.

By 1475 the island of Fernando Po and the southerly trend of the coast at the end of the Gulf had been discovered as far as Cape Catherine in latitude 2* S.. Over 2,000 miles of coastline had been explored in six years.

Then war with Castile broke out waged savagely in the Gulf until the Castillian fleet of thirty-five sail was defeated there in 1478. As aresult of this naval victory at the Treaty of Alcáçovas in 1479 Castile, while retaining her rights in the Canaries, recognised the Portuguese monopoly of fishing, trade and navigation along the whole West African coast, and Portugal's rights over the Madeiras, Azores and Cape Verde Islands (42).

The task of exploration was now taken over for the Crown by the heir to the throne. He, on succeeding as King John II in 1481, immediately ordered the building of a fortified trading post on the Gold Coast, Sao Jorge de Mina — el Mina — where, as importantly as protecting the trade in gold, slaves and pepper ships could also water and refit in safety before setting out on their long and arduous voyages home — or even more arduous Southerly voyages of exploration.

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(40) [G. R. Crone, *America*, 39.]

(41) [A. Cortesão, *op. cit.*, Vol. II, 172-80 (176).]

(42) [J. H. Parry, *The Discovery of the Sea*, 110-11.]

I rate King John II, 'the perfect prince', with the Infante and Dom Pedro as a key man of vision and of strategic insight and action in the history of Portugal and the sea. Once again, the unpredictable factor, personality, shapes history.

Once again, too, the initially unrewarding task of exploration was to be at the Crown's expense, as had been the pre-fabrication, transportation and erection of the fort to protect the sheltered berths at el Mina. The ventures were fitted out at royal expense, equipped for exploration not trade — they carried stone *padrões* to mark their discoveries, and were manned by sea captains of skill and experience in the service of the crown, Diogo Cão and Bartolomeu Dias. Their object now there can be no reasonable doubt, was to reach the Indian Ocean (43).

Cão set out on his first voyage in 1482 from Lisbon. He called in at el Mina then crossed to Cape St. Catherine, thence he sailed South down an unknown coast, discovering the great Congo River, turning back from Cape St Mary in latitude 13* 26' S. to Lisbon. There, on arrival early in 1484, he was made a national hero in the belief that he had «reached almost to the *Passum Promontorium*, where the Barbarian Gulf begins», as King John II informed the new Pope (44).

In the autumn of 1485 Cão was despatched again only to turn back at Cape Cross in latitude 22* S. with the coast still trending to the South. His fate is unknown but his expedition returned to Lisbon to report the failure to round Africa.

Similarly, two non-Arabic speaking Portuguese sent by the king in 1485 or 1486 to reach Prester John by land wisely turned back on reaching the Levant.

But the king was resolute. This time he dispatched a Portuguese, Pero da Covilhã, who could pass as a Muslim and a companion, Afonso de Paiva. Their reports of their travels were to reach King John II by 1491.

Leaving Portugal in 1487 they covered the major ports around the Indian Ocean, from Sofala on the S.E. coast of Africa, in latitude 20* S., to Malindi in 3* S., Aden and Hormuz controlling respectively the straits into the Red Sea and the Persian Gulf, through which the spices passed by sea to the Levant for Europe. They went down to Calicut and the coast of Malibar on the Southwest coast of peninsular India, the focus of the spice trade in the Indian Ocean.

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(43) [E. Axelson, «Prince Henry the Navigator and the Discovery of the Sea Route to India» (*The Geographical Journal*, June 1961). Vol. CXXVII. Part 2, 146-58 (150-54).]

(44) [J. H. Parry, *op. cit.*, 125.]

It was in the same year 1487 that King John II despatched Bartolomew Dias to attempt what Cão had failed to do — round the seemingly endless South-western coast of Africa and reach the Indian Ocean.

The Art of Navigation, c. 1400.

How, during these 200 years were these ships navigated?

We are able to satisfy our curiosity thanks to what I regard as the culminating researches of, in particular, the late Professor Eva Taylor, of Professor Frederic C. Lane and of our President, Professor Luís M. de Albuquerque (45).

By the time of the Vivaldi brothers' voyage of 1291 Genoese and Venetian and Catalan pilots navigated mathematically, that is they had written sailing directions which gave them the magnetic bearings and estimated distances of places from Cape St Vincent clockwise within the Mediterranean and Black seas and down the african Atlantic coast to Safi; they had a manuscript vellum bearing and distance portulan chart, on which the foregoing information was delineated to scale accurate to quite a small percentage, with an appropriate distance scale and a network of directional lines; two pairs of dividers; a straight edge and piece of lead with which to plot on the chart the ship's progress; a sandglass for measuring the passage of time in order to calculate periodically the distance sailed from the speed — estimated by eye — of the ship through the water (46); a trigonometrical table, the *toleta de marteloio,* with which to calculate, using Arabic numerals, the courses and distances to be sailed to make good a particular track when the wind was adverse; and the master instrument, the basis of all this recently developed art of navigation, a magnetic compass; perhaps also a piece of loadstone with which to re-magnetise the soft iron needle of the compass from time to time during a long voyage (47).

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(45) [E. G. R. Taylor, «The navigating manual of Columbus» (*Jour. of the Inst. of Navigation,* January 1952) 42-54 & «Mathematics and the Navigator in the Thirteenth Century» (*Jour. of the Inst. of Navigation,* January 1960). Vol. XIII, No. 1, 1-12 & Foreword; F. C. Lane, «The Economic Importance of the Invention of the Compass» (*American Historical Review* (April 1963) Vol. LXVIII, No. 3, 605-17; L. de M. Albuquerque, *Curso da História da Náutica* (Coimbra, 1972.]

(46) [D. W. Waters, «Early Time and Distance Measurement at Sea, *Jour. of The Inst. of Navigation,* Vol. VIII, No. 2, April, 1955, 153-73, ascribes invention of the sandglass to the Venetians in the XIIth century as a shipboard timekeeper for navigation. I omitted my source for citing the secret Egyptian and Catalonian method of making soda ash, used to make glass, and to the commercial ties between Catalonia and Venice mutually influencing their designs in glassware. However, I have a record that, «Flint glass was a ninth century Cordoban invention», and that in the XIth century skilled craftsmen made glass in Islamic Spain prized throughout northern — Christian — Spain, which was enriched by tributary gold from the Muslim dominions, where there was a remarkable cultural flowering, G. Jackson, *The Making of Medieval Spain* (London, 1972) 22, 54, 58. This supports indirectly that sources of Venetian skill in glass-blowing were Catalan as well as Levantine — especially Tyre, the centre of the Syrian glass industry, captured 1124, thanks to the Venetian fleet, and where the Venetians gained great trading concessions.]

In the late xiiith century Portuguese shipmasters probably used a ship's compass (48), probably reckoned distances sailed in days of sailing and estimated smaller distances, like their Northern brethren, by smaller intervals of time measured by sandglass (49). They had no charts and most probably relied on memorised features of past voyages for sailing directions, as they did for recognising landfalls and coastal features. Hence the importance of long apprenticeship at sea.

In the Prologue to *The Canterbury Tales* Geoffrey Chaucer described an English shipmaster of the 1390s and I see no reason to doubt that he would have described a Portuguese shipmaster in the same terms. He wrote:

> «A shipman was ther, ...
> ... to rekene wel his tydes,
> His stremes and his daungers him besydes,
> His herberwe and his mone, his lodemenage,
> Ther was noon which from Hull to Carthage.
> Hardy he was, and wys to undertake;
> With many a tempest hadde his beard been shake.
> He knew wel alle the havenes, as they were,
> From Gootlond to the Cape of Finistere,
> And every cryke in Britayne and in Spayne; ...» (50)

Unlike their contemporary Mediterranean shipmasters both had grown up with the twice daily rise and fall of the tides and change of speed and direction of the tidal streams, deadly to the unwary in Atlantic coastal waters — Lisbon, indeed the coast from Lagos to La Coruna, has a tidal range of around 12 feet — 2 fathoms, whereas in the Mediterranean it is from 1 to 2 feet — barely measurable with a lead and line, the instrument used to take soundings — the depth of water and nature of the seabed. In contrast at Hull it is 23 feet, at Bristol it is 42 feet, seven fathoms; the tidal streams are correspondingly fierce, up to 5 knots — five sea miles an hour — in the Bristol Channel or, as in the Mediterranean, negligible (51).

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(47) [E. G. R. Taylor, «Mathematics and the Navigator in the Thirteenth Century», *op. cit.;* F. C. Lane, «The Economic Meaning of the Invention of the Compass», *op. cit.*.]

(48) [The earliest record appears to be one of 1414. L. Mendonça de Albuquerque, *Curso de História da Náutica*, 18.]

(49) (D. W. Waters, *The Rutters of the Sea*, New Haven and London, 1967, e.g., «a glas or two» (188, Direction No. 19); see, «Appendix 4, 433-37 (433) & Appendix 6, 442-48 (442), where Portuguese sailing directions originating in the «fourteenth century at least» are identified.]

(50) [*N.* W. Skeat, *The Complete Works of Geoffrey Chaucer* (1949) lines 390, with omissions, to 410; herberwe = harbour; mone = moon; lodemenage = pilotage; Carthage = Cartagena; Spayne = Spain and Portugal.]

(51) [*Brown's Nautical Almanac Daily Tide Tables for 1963*, Glasgow, and *Brown's Tidal Streams...*, Glasgow, 1963.]

Chaucer was a contemporary of Abraham Cresques of Majorca, credited by Armando Cortesão with constructing the famous Catalan atlas with its world map of 1375 already discussed (52). This contains the earliest known diagrammatic tide table which, with its supporting text, bears out the unimportance of tides within the Mediterranean Sea and the importance of knowing their state when outside it, for it gives tidal establishments from the Strait of Gibraltar Northwards only, to the Strait of Dover (53).

Chaucer was not just a poet, he was also a mathematician, astronomer and a courtier. He married the sister of the third wife of John of Gaunt, grandfather of the Infante on his mother's side, Philippa of Lancaster whom Chaucer knew well (54).

Professor Taylor suggested that Chaucer may well have influenced Philippa in the way she educated her sons and that he might have seen the tide table «when he visited the French Court, for he placed the story of the lady who would yield her virtue only if the rocks disappeared precisely on Penmarch Point» (55).

I have spent some time on tides and tidal streams because it was their absence in the Mediterranean which made it practicable in the mid-XIIIth century to exploit within that sea uniquely the directional property of the magnetic compass mathematically; that is, to construct accurate bearing and distance charts, to develop the science of, in one word, hydrography; and to invent the means to begin to use it scientifically, the art of, in another single word, navigation, an art fundamentally distinctive from the age old art of pilotage, of coasting.

Let there be no mistake about it, like hydrography, the art of navigation was fundamentally new. This is because it was based similarly upon the measurement of direction by a self-orienting instrument, the magnetic sea--compass, sub-divided mathematically so as to indicate or measure precise standardised angles (128 points in all) around the compass (horizon) at intervals of 2* 3/4 — from a universally standard (as it was believed) direction, magnetic North; and navigation was similarly based upon the mathematical measurement of distances by the use of a unit of standard length, the mile, and the passage of equal intervals of time by means of that self-registering instrument of the passage of time, the sand-glass.

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(52) [A. Cortesão, *op. cit.*, Vol. II, 44-8, especially notes 112-18.]

(53) [See H. D. Howse, «Some Early Tideal Diagrams», *Revista da Universidade de Coimbra*, Vol. XXXIII, 1985, 365-85 (366-69).]

(54) [E. G. R. Taylor, *op. cit.*, Foreword.

(55) E. G. R. Taylor, *The Haven Finding Art*, London, 1956, 136-40, (138) where there is also a useful intrepretive diagram of the Catalan tide table. Pte. de Penmarch is only a few miles S. E. of Chausé de Sein («Sayn» in the Catalan diagram); she also gives an anecdote of 1324 which suggests strongly that Genoese shipmasters made good use of a tide table to avoid unwelcome attention from English troop transports in Falmouth.

The history of knowledge of the tides is well given in M. Deacon, *Scientists and the Sea 1650-1900*, London and New York, 1971, 3-38, «The Ancient World» and «The Middle Ages».]

The fact that these measuring devices were imperfect should not be allowed to obscure the fact that they were scientific in principle — to-day's measuring devices are being refined at this moment, the advancement of science is based upon refinement of measurement, nor that their use was scientific in intent — on the one hand to construct accurate charts of the seas to be navigated and their coasts and islands, on the other to use them repeatedly, accurately, so as to go in a safe and timely manner from one port of call to another.

Thus it was in the Mediterranean and could only have been in the Mediterranean, the tideless Middle Sea, that navigation was developed, the art of conducting mathematically any seaworthy ship in any desired direction over great distances, out of soundings, under overcast skies for long periods of time, from one assigned place to another, propelled by the wind and sometimes, as when entering port, by oars.

Once acquired the art, fully developed within the Mediterranean by the 1250s, could be adapted for use outside its virtually tideless waters in the tidal waters of N.W. Europe (56).

This began in 1277 when Genoese galley masters began making commercial contracts to voyage directly into the English Channel, voyages which became regular the next year. The spur to making this direct maritime link between the Mediterranean and the North Sea, which has been well described as «one of the crucial events of European history», was the acquisition by the Genoese Zaccarias family of concessions of the most important alum quarries, at Phocaea, on the Aegean coast of Asia Minor. Alum was indispensible to dye the best cloth, the cargo became one of the foundations of Genoa's economic strength, of Bruges's prosperity and a significant factor in the growth of the cloth trade in Northern Europe (57).

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(56) [In his fundamental study of the invention of the magnetic sea compass Professor Lane was «inclined to... assign to 1300 or thereabouts the attachment of the compass card to the needle, ...» (F. C. Lane, *op. cit.*, 616.). However, it can be reasonably deduced that the sea-compass with the needle attached to the card had been developed in the Mediterranean by c. 1250 at the latest because it was about this time that the earliest known *compasso da navigare* (book of written sailing directions, literally, 'sailing around book') containing compass directions was compiled. (B. R. Motzo, *Il Compasso du Navigare opera Italiana della metà del secolo XIII* (Cagliari, 1947). Directions between places were given to within less than 3* (128 rhumbs of 2* 48' 46"). Such accuracy would have been impracticable without the prior development of an instrument such as the sea-compass capable of measuring with this accuracy (no other is known); furthermore, such accuracy could have been of no practical use to seamen who had no sea-compass comparably sub-divided with which to set course and keep it. Moreover, the earliest reference to the use of a chart at sea — during St Louis' voyage from Aigues Mortes to Tunis — is 1270 and is in terms that imply its use was already customary. (E. G. R. Taylor, *Haven-Finding*, 109).]

(57) [R. Doehaerd, *Les relations commerciales entre Gênes, la Belgique et l'Outremont d'après les archives notariales gènois aux xiie et xive siècles*. Vol. 1 (Brussels, Rome, 1941)

It is to be remarked that it was in the XIIIth century that, with the acquisition of the magnetic compass, mechants began to ship their goods between the North Sea and the Baltic by the all-sea route around the Skaw instead, as hitherto, by using the Lim Fjord and, before that, portages near Hedeby and/or Lubeck across the neck of the Danish peninsula. The compass thus enabled ships to traverse the German Bight with the necessary reliability to ensure commercial confidence in such ventures.

In fact, combined with the lead and line the sea-compass made commercially practicable what had hitherto been impracticable, direct commercial voyages across the Bay of Biscay from Cape Finisterre to the Soundings — the 100 fathom line — in the Western Approaches to the English Channel. It was surely the sea-compass that gave the Vivaldi brothers the confidence to attempt to sail around Africa in 1291, and which encouraged King Dinis (1261-1325, reigned from 1279) at this time to encourage Portuguese trade across the Bay. Whether his Genoese pilots taught Portuguese seamen to navigate with more than the sea compass is not known (58).

Certainly, the sea-compass makes explicable the re-discovery of the Guanchos inhabited Canary Islands by the Genoese Lanzarotto Malocello about 1336 when in the service of the Portuguese king, from whom he received a feudal grant of Lanzarote and Gomera, though settlement was not successful until 1402, it will be recalled.

The lack of the sea-compass also explains why Atlantic exploration was so long delayed. Of course, the cost of initially uneconomic exploration is another, along with the need for suitable sailing craft.

The fact is, it was not until the 1420s, when the Portuguese State, in the person of Prince Henry with his fundamentally State authority and finances, ces, undertook exploration by sea that it became practicable. Only the State could afford to send forth the expensive and uneconomic ships needed, the expensively equipped seamen; for the pilots Prince Henry sent out certainly had their charts as well as sea-compasses and sandglasses (59). We can therefore be as sure that they had also trigonometrical tables, the *toleta de marteloio*, plotting compasses and written sailing directions for, without all these, the chart was useless.

We also know that at night the pilot took the time from the position of the two bright Guard stars, of which the foremost, *Kochab*, is the brightest,

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No. 334, 17 April, 1277; R.-H. Bautier, *The Economic Development of Medieval Europe* (London, 1971, 128-31 & 136.]

(58) [A. Cortesão, *op. cit.*, Vol. II, 6-7.]

(59) [M. Godinho, *Ensaios* (Lisboa, 1968), «Sobre historia universal navegação oceanica», 179-227 (196), citing a record of 3 sea compasses, a sandglass and two sounding leads and lines in the *Sam Cristovam* in 1416. The earliest documentary evidence of charts of Portuguese construction are 1435 and 1443, the earliest signed one surviving is of 1483 (by Pedro Reinel), the earliest signed and dated is by Jorge de Aguiar, 1492. Neither has a scale of latitude. See A. Cortesão, *op. cit.*, Vol. II, 118, 207-11, Fig. 88 & 211-16, Fig. 90.]

in the constellation of the Little Bear as they appeared to rotate around the less conspicuous pole Star in its tail. To do these he had long had 'Rules', which he learnt by rote. They were based on the monthly midnight position of the Guards as they changed in the course of the year. These were given with a wheel-like circular monthly calendar in the Catalan atlas of 1375, but the seaman, as Professor Taylor lucidly explained, imagined:

«A giant figure [,] whose outspread limbs just reached the circle of the front Guard [,] was imagined to look down from a position just covering the celestial pole (then still identified with the North Star). The head, the right arm, the feet and the left arm marked the four seasonal positions of the clock hand at midnight in mid-April, July, October and January respectively. A pair of cross lines between the limbs completed the eight equal divisions of the circle...» (60)

By day to find the time the pilot took the compass bearing of the Sun.

The Portuguese development of oceanic «altitude» navigation.

To sail back from the Canaries (of which Lanzarote and Las Palmas are only 60 miles from Cape Juby on the Saharan coast), which began to be settled successfully from 1402 under a Castillian grant, the prevailing wind — here N.E. — and the limitations of their vessels' rig combined to force the pilots, like those of the expeditions of the XIVth century, to sail N.W., the wind abeam far out into the Atlantic. Parry has reckoned a long board about 300 miles N.W., then a longer board of nearly 600 miles N.E. would return them most directly to Portugal. Unavoidably this would take them close to the uninhabited Madeiras, 300 miles N.W. of the northern tip of Lanzarote and over 300 miles from the mainland coast. This would account for their discovery in the preceeding century and re-discovery about 1419 followed by settlement from about 1420, for Portugal was now able to acquire as well as interested in acquiring new territories.

But the adverse wind for a return voyage from these islands to Portugal is not the only physical factor making it difficult. Unsuspected by these pioneer navigators there is a clockwise circulation of the waters of the North Atlantic, which could not be identified until accurate position finding at sea became practicable at the close of the XVIIIth century.

Off Portugal the current flows to the South at from 8-12 miles a day, by the time it is passing the Madeiras and the Canary Islands it is flowing to the S.S.W.. The Canary Current, as it is now called, thus combined with the N.E. Trade wind to carry the ships farther into the Atlantic than they reckoned, using their *toleta de marteloio*, for this gave them only relative courses and no means of checking the estimate of distances sailed along them. The farther to the N.W. that a ship sails from these islands the more Westerly is the Currents' direction, the farther to the West as well as to the South is the unsuspecting mariner carried.

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(60) [E. G. R. Taylor, «The navigating manual of Columbus», *op. cit.*, 44 & Fig. 1.]

It is reasonable to assume on the grounds of practical seamanship that the Madeiras were found in this way in about 1336 by a Genoese ship making the passage home from the Canaries. Similarly, again on the grounds of practical seamanship and the limitations of the 'closed sea' navigational methods used in these 'open' — oceanic — seas, it is certain that ships discovered one or more of the Azores when sailing Northward bound from the Canaries or the Madeiras. They did this necessarily on beam winds and under the influence of unknown currents, sailing alternately out into the ocean, then back towards the mainland to 'make good' a N. Easterly track towards Cape St Vincent, their infallible landfall, and so to their home port. Certainly Azorean islands are shewn, as already discussed, on XIVth century charts. The earliest, by the Pizzigani brothers of 1367, shows an island that has been identified as Terceira. The islands of the various archipelagos are shewn in the charts in various positions North — South and somewhat closer to the mainland than in reality they are (61).

This in itself is proof of the limitations of the 'closed sea' navigational methods used by the pilots in the ocean. They were reliable only in the Mediterranean and across the Bay of Biscay. The result of this navigation which did not take into account the effect of ocean currents, indeed could not for they were unknown, was to misplace a ship's position in both a North-South and in an East-West direction. The displacement varied on each voyage depending upon such factors as weather conditions experienced and length of time spent sailing out of sight of land and out of soundings whilst subject to currents whose velocity varied continually according to wind force and direction and other factors. Consequently, a pilot might sight an island in a different 'estimated' position on different voyages; or pilots in different ships might sight the same island and plot its «estimated» position in a different position, according to their individual 'dead reckoning'.

A classic example of this nature occurred as late as 1758. A British squadron left Kinsale in Ireland for the West coast of Africa. Some fifteen days later before dawn the flash of distress signals was seen. At daylight the ships were amazed to see land ahead, which they could scarcely believe as they thought they were far to the Westward until they saw one of their consorts, the *Lichfield*, ashore. In all three ships were lost. The reckoning kept in every ship was false (62).

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(61) [Since I wrote the above I have discovered that another sailor, Admiral Coutinho, also considered that the discovery of eastern and central Azores was made by accident by ships returning from the Canaries or Madeiras', D. Peres, *A History of the Portuguese Discoveries* (Lisboa, 1960) 31 for the Atlantic islands as shewn in ten charts up to *c.* 1400 and named in a Ms. of *c.* 1360 see, Armando Cortesão, sketch charts and list in his *History*, Vol. II, 55-70, Fig. 70 and Table I.]

(62) [National Maritime Museum, Greenwich, Ms. PAw/1.]

A hydrographic example of the consequences of inability to measure distance 'made good' East-West, was the double charting of «Frobisher's Strait» in the 1570s. Into the xviiith century it is shewn, in effect, in both Baffin Land, where it is now known as Frobisher Bay, and in Greenland some 500' (800 km) nearer to the British Isles than in reality (63).

Pilots returning from the Canaries made the mainland sooner or later. It was known to lie for certain to the Northeast or East, so a landfall was unavoidable. This was never the situation when looking for a lone island or for the scattered islands of an archipelago in the ocean, such as the Azores. Then it was hit or miss with the probability of missing far greater than the probability of finding an island again in the vast spaces of the ocean for, within a matter of days, a pilot could not be sure whether it lay to the West or to the East of him, let alone whether to the North or South.

Again, there is a classic example to illustrate this, again from the xviiith century.

Commodore Anson's squadron was in the South Pacific in 1741. They were heading North for the island of Juan Fernandez when Cape Noir was unexpectedly sighted at one in the morning on April 13th. This was the first indication that the ships had been set some 300 miles to the East by strong currents (64).

Such examples of ocean navigational limitations up to the latter half of the xviiith century, confirm the above explanation of the discovery of the Azores in the xivth century, viz., by ships returning from the Canaries and Madeiras.

This occurred because the Easternmost of the nine islands, Sta. Maria, lies 800 miles to the West of Cape St Vincent. As a consequence, until the Canaries were re-discovered in 1336, Sta. Maria and the rest of the scattered archipelago, was unknown. This was not merely because of their distance from the mainland but because the prevailing winds off Portugal are Northerly and the Azores lie in a belt of variable winds which are predominantly Westerly and Northerly. So, even when the existence of the Azores is known they are approached from Portugal by sailing ships most easily by sailing South, then West, then North.

The fact that Gabriel de Valseca positioned the nine islands of the Azores for the first time much nearer their real positions in his chart of 1439 has navigational as well as hydrographic significance (65). Indeed, it is the navigational significance that is of the greater importance for the chart reveals that it was by then navigationally practicable to be sure where the islands really were in the ocean in a North-South direction, though not in an East--West direction. Also, the inscription identifying the «discoverer» and giving the date of his re-discovery, 1427, means unequivocally that the navigational means to locate individual Azorean islands consistently had been developed by then, for the seven nearest islands of the Azores are some 200 miles apart Northwest-Southeast and 150 miles apart North-South; some are out of sight of one another.

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(63) [See, for example, R. A. Skelton, *Explorers' Maps* (London, 1970) Fig. 77, the North-west Passage in the Molyneux globe of 1592 and R. A. Skelton, *Decorative Printed Maps* (London, 1965) Pl. 76, The World, by G. and L. Valk, Amsterdam, *c.* 1690, in Schenk's *Atlas Contractus.*

(64) [National Maritime Museum, Greenwich, Ms. ADM/L/G/53.]

(65) [In the Biblioteca Central, Barcelona; see: A. Cortesão, *op. cit.*, Vol. II, 148-50, Fig. 77.]

By 1439 (at the latest) Azorean islands are for the first time, as already remarked, charted close to their correct positions, by the Majorcan hydrographer Gabriel de Valseca. This was the year in which the Regent granted the Infante their Lordship, when settlement and trade quickly followed. As in the Madeiras, over which the Infante also had Lordship, it was profitable, helping to finance exploration. Settlement and trade were the result of reliable oceanic navigation. The two Northwesternmost islands, Flores and Corvo, 100 miles Northwest of Fayal, were re-discovered from the Azores in the 1450s.

Just as the Madeiras provided invaluable ports of call for outward — Southward — bound ships so did the Azores for ships homeward — Northward — bound whether from the Canaries or Madeiras or from the African coast as this was explored to the Southward. Moreover, having made the Azores the returning voyager had the assurance when he took his departure, particularly when the skies were obscured, that he was indeed in the correct 'height' to make the 1,000' distant landfall of either Cape St Vincent or the Rock of Lisbon, both reached on Easterly courses.

It seems to me beyond reasonable doubt that once the Madeiras were settled it was the need for a reliable means of measuring how far *North* a Portuguese ship had sailed returning from them that made oceanic navigation a *necessity*. The pilot *had* to know at what point in the ocean he should steer East to make his intended landfall on the mainland. This need inspired the first and fundamental development in ocean navigation; or, concurrently, it was the realisation that any ambitions that the Infante Henry had by then to explore to the South of Cape Bojador presupposed as a prerequisite the availability of a means to ensure that successful explorers would return to Portugal in a safe and timely manner to tell their tale.

That development of the means to return from South of Cape Bojador pre-dated the rounding of the Cape is not accorded the importance it merits. Yet 'the proof of the pudding is in the eating'. Once the navigational means was found to fix the position of islands in the ocean once and for all time rediscovery — in 1427 — and prompt settlement of the remote, hitherto too difficult to fall in with Azores to be certain where they were, followed almost immediately. At last the islands could be reached infallibly. Settlement and trade followed within a dozen years — and the rounding of Cape Bojador — in 1434.

The Azores were reached from Portugal by sailing vessels most speedily and easily, it is worth repeating, by sailing South, then West wind abeam into the empty wastes of the Atlantic, then North on the wind, always, day after day, out of sight of land from the point of departure until islandfall — if it were made. Returning from West Africa a similar track *had* to be followed. The great problem for the pilot following either track was, «When to alter course to East?»

Either the need to be sure of returning from beyond Cape Bojador or the desire to occupy the re-discovered Azores — it is really immaterial which — inspired the development of oceanic-astronomical-navigation. It was developed before the Southerly coastal exploration of West Africa, which has attracted so much attention because of the glamour of gold associated with it. Only after that push South began did it become the most powerful incentive to develop further the utility of oceanic navigation and of hydrography.

In this reasoning I am, I find, at one with the late Commandante A. Fontoura da Costa, to whom all scholars must forever be indebted for his encyclopaedic *A Marinharia dos Descobrimentos*, for in this he wrote (according to my translation):

«An interesting problem is that of the astronomical observations of the discoveries, in the xvth century... they must have begun... following the discovery of Madeira, possibly in 1420 or a little later, coincidentally with *mestre Jacome* coming into the service of the *Infante*...» (66).

The charting and naming of the islands of the Azores in the xivth and in the xvth centuries merits systematic re-studying in the light of appreciation of the prevailing navigational limitations upon accurate position finding in the ocean. Armando Cortesão's work on the identification of charted Atlantic islands is basic, and I have relied heavily upon it in making my deductions. Further research as suggested should substantiate them and narrow the date span of the introduction of 'ocean-astronomical-('altura') navigation'.

For any ship exploring or trading at points on the coast of Africa as it was discovered the adverse winds for returning North off that long coast continued to force the pilot to follow the *volta do mar largo* — the great sweep to the West and North which eventually brought him home by way of the Azores.

Moreover, as another sailor, Admiral Teixeira da Mota, stressed, the farther South the explorers pressed down the African coast the longer became — the farther to the West stretched — the *volta do mar largo* (67).

Recently, I questioned one of the most experienced singlehanded Atlantic sailors of to-day, Michael Richey, about the navigational problem of repeatedly reliably finding the Azores from Portugal. Quite fortuitously he had just completed a singlehanded summer voyage from Nazaré, in Portugal to San Miguel and thence home to England. He wrote:

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(66) [A. Fontoura da Costa, *A Marinharia dos Descobrimentos* (Lisboa, 1939) 35.]

(67) [A. Teixeira da Mota, *A Evolução da Ciência náutica durante os séculos XV-XVI na cartografia Portuguesa da época* (Lisboa, 1961) 7.]

«No, I don't think you exaggerate the difficulties but they might be lessened by the skill of the pilot who would know what to look for. Most of the islands are pretty high and in good weather would be visible 40 or 50 miles off. In fine weather cloud cover would give a fairly good indication of where an island lay. Land birds appear a certain distance off and so on. Again, I would have thought the skilfull pilot would acquire a pretty good idea of the set of the current.»

However, he added a very pertinent point of seamanship that I had not mentioned and have not hitherto stressed — there is no mention of these early voyages having been made in caravels (they were first mentioned in 1441) but that there is of the squarerigged *barcas* which could be sailed little if any closer than 90* to the wind:

«I suspect that the ability to tack, even at so broad an angle [I gave 90* made good, also based on the ability of a traditionally built Omani lateen rigged dhow to sail on the N.E. monsoon], was what gave altitude navigation its real edge because altho, the prevailing wind might be against you, in fact you sail on the wind that happens to be blowing. To make intelligent use of the wind a knowledge of where your destination lies even in so simple a form as its «altura» is obviously of great importance.»

«In short my guess would be that you are right, but unless there is some sort of documentary proof, you just could be aawrong.» (68).

Along the African coast the problem was primarily one of identifying landfalls within soundings, in the ocean the problem, whether returning from Africa or outward bound for an Azorean island, was primarily one of finding a small island hundreads — not less than 800 and up to 1,100 — miles from the mainland and out of soundings, certainly until within visibility distance.

Before 1436 ships had already been carried hundreds of miles South and West of the Azores to the Eastern edge of the Sargasso Sea in their efforts, no doubt, to find one or other of the Azorean islands, for *mar de baga* is inscribed on a chart in the atlas of that year by Andrea Bianco, signifying that 'sea' (69).

There could be only one practical solution to the problem of finding repeatedly specific islands in the ocean sea. That was to use the only objects visible to the seaman's eyes wherever he was in the ocean, provided the skies were clear. These were the socalled 'fixed stars', of which the most obvious, particularly in these lower latitudes where stars are so bright, was the familiar to the pilot as well as conspicuous constellation of the Little Bear, with its

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(68) [Letter of 22 September, 1987, to D. W. Waters.]

(69) [A. Cortesão, *op. cit.*, Vol. II, 142; the atlas is in the Biblioteca Marciana, Venice.]

Guards revolving nightly around the North-pointing Pole star, the *Stella Maris* of seamen since Classical days.

The North star, being close to the North polar axis of the heavens, appears high in the sky in high North latitudes and closer to the horizon the farther to the South the observer proceeds. This had been well-known to the educated since the English scholar Sacrobosco had described it in his highly popular, much copied *De Sphaera Mundi* (derived from Ptolemy's IInd century *Almagest* or *Astronomy*) in the middle of the xiiith century. In this he described finding the latitude of a place, its angular height above or below the Equator measured from the centre of the earth by means of a quadrant. This raising and laying of Polaris (treated as that of the true Pole) was no doubt known empirically to seamen from their voyaging, but was of no practical value in a sea like the Mediterranean where, «no great errors arose since most days they had sight of the land and knew where they were», as Pedro Nunes was to express it, in the 1530s (70).

In the ocean, «where only water and heaven may be seene» by «a shyppe engoulfed», as Martin Cortes was to express it in 1551, it was another matter, a matter of life or death, «to bryng them into the waye that wander.» (71)

Which is why the Infante, well versed in astronomy and astrology showed such a grasp of the fundamental problem of exploiting discoveries in the sea when, after the discovery (1420) of Madeira, he obtained the services of Master Jacome of Majorca; for Master Jacome was skilled in making instruments of measurement as well as charts, and in the art of navigation (72) as well as in the science of astronomy.

A solution to finding an elusive island in the ocean was to establish at what height a star on the observer's meridian was seen above the horizon. A pilot could be taught to use this knowledge to make his problem of searching for the island systemmatic instead of largely at random, as hitherto. The search then became an arithmetical exercise (to which he was accustomed from use of his *toleta de marteloio*) based upon positional astronomy (to which he was also familiar thanks to the star clock) to get his ship into and keep in the measured 'height' of his intended landfall. Only then had he to begin to look out for it, when he then began to sail towards it East or West, as appropriate, in that 'height'. Sooner or later — preferably later, to avoid an unexpected sighting and unavoidable stranding — he was bound to sight the land or island.

Thus was begotten, I submit, the new navigation, oceanic astronomical navigation, and the new — Portuguese — science, nautical astronomy.

In the above description of 'altitude' navigation in search of an island in a known 'height' «Only... when he... began to sail towards it East or West, *as appropriate*» is a very important qualification. If the pilot under estimated the amount of Easting or Westing his ship had made and altered course to the West or to the East, as he reckoned «appropriate», in order to run down the island in that 'height', he would never find it on that course.

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(70) [L. de Albuquerque, «Astronomical Navigation», in A. Cortesão, *op. cit.*, Vol. II, 227.]

(71) [M. Cortes, *The Arte of Nauigation* (London, 1561) fol. iii *verso;* it was first published in Castillian in Zaragoza, 1551.]

(72) [A. Fontoura da Costa, *op. cit.*, 10.]

This mis-reckoning of distance 'made good' in an East or West direction (in longitude), of which an example has already been given in a different context, was not infrequent.

Thus, again in the course of Anson's voyage in 1741, crew were dying daily from scurvy when *Centurion* left the island of 'Succoro, off the coast of Chile in lat. 46* 06' S., for the island of Juan Fernandez, 700' to the North. Britain being at war with Spain the coast of Chile was hostile. Anson therefore *had* to reach the island to save what was left of the ship and crew.

Centurion reached the island's latitude fifteen days later. The log reads:

«May 28th 1741 ... looked out all night for the island of Juan Fernandez imagining ourselves near the meridian. AM. being in the parallel of latitude ['height'] ... Conceiving we had sufficient westing we hauled up to the East by North intending to keep in the parallel of 33* 30' S.»

«May 29th. ... in hopes of making it soon ... our people being grown to the last degree infirm and sick ... falling down hourly. AM. seeing no sight of land began to give it up, and concluded we had not had sufficient westing, but were now gone to the eastward of it, but as this thing was uncertain continued on our course eastward knowing we must either fall in with it soon or make the Continent...»

For two days they ran before a following breeze, then sighted the Andes mountains!

«June 8th... At the break of day discovered the larger of the two islands of Juan Fernandez 11 or 12 leagues...»

«June 11th... Anchored at Juan Fernandez Bay...»

Thus, this mis-reckoning in longitude by the Master forced the *Centurion* to spend a further fourteen days in the ocean searching for the island. It cost the lives of 100 men! (73)

So, in the 1420s the Portuguese oceanic pilot was taught, *as he had to be to find oceanic islands infallibly* to look at stars, those in the Little Bear especially, differently, not just to tell the time but to find their height above the horizon. For altitude navigation as a practicable means of position-finding in the ocean was initially the simplest possible adaptation for seamen by astrologers of the seaman's long familiar use of *Kochab* for time-telling. In addition to using the Guards' positions relative to Polaris to 'tell the time' the pilot was taught to use it to 'tell his height' by the Guards, always observing them in the same position — 'the Guards in the Head', for example, as still used decades later — in 1498 — by Columbus on his third trans-Atlantic voyage (74).

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(73) [I. Heaps, *The log of the Centurion* (London, 1974) 91, 98-100, 109.]

In the 1420s, indeed, for fifty years after that the pilot had no conception of 'latitude', nor any need for it. Latitude was something astrologers and astronomers used in their esoteric arts but not for position-finding, neither cartographically nor hydrographically, that is, until, at this very conjuncture, Ptolemy's *Cosmographia* was recovered for the West (1406) with its maps with latitude and longitude defining the position of a place, but it would be the 1480s before these would be used in sea charts, later, in maps.

The pilot's measuring instrument if, at first, not merely an outstretched hand and arm, was of the simplest form, a hand quadrant, used in the West since the XIIIth century by astronomers such as Sacrobosco; the simplest not merely because it was the easiest instrument to make — from a piece of wood, a short length of silken cord and a piece of lead — but because for a given radius the largest scale possible of 0°-90° could be drawn or incised upon the rim of its arcuate edge, and place names could be written upon it legibly at various heights by the pilot himself. It was easy to use, given a reasonably stable platform; the pilot sighted the star through two pinnules on one of the radial edges, an assistant read off where the plumb-line cut the scale.

On the degree scale could be marked the already known 'height' of places, and the 'height' of any discovered or called at for the first time which the pilot oberved himself. So it served both as a gazetteer and a 'height' measuring and 'height' recording instrument. It also enabled the pilot, by observing his height at sea to get into the known 'height' of his destination and to reach it by sailing East or West along this periodically verified 'height' until he made his intended landfall. In short, like his contemporary master pilot in the Indian Ocean the Portuguese pilot of the early XVth century sailed by «altitude» navigation (75).

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(74) [E. G. R. Taylor, *op. cit.*, 46.]

(75) [See A. Teixeira da Mota, *Méthodes de Navigation et Cartographie Nautique dans l'Ocèan Indien avant le XVI*^{e} *Siècle* (Lisboa, 1963); L. M. de Albuquerque, *O Livro de Marinharia de André Pires* (Lisboa, 1963) 133 *seqq.* and 217; L. M. de Albuquerque and J. L. Tavares, *Algumas observacoes sobre o planisfério 'Cantino'* (Coimbra, 1967); G. R. Tibbetts, *The Navigational theory of the Arabs in the fifteenth and sixteenth centuries* (Coimbra, 1969); he uses «latitude» in places where «altitude» is meant. Arab navigators did not relate their positions to latitude but to the altitude of certain stars. For a modern account of sailing by altitude navigation see T. Severin, *The Sinbad Voyage* (London, 1984). The antiquity of 'altitude' navigation in Eastern seas is ill established. Needham writes: «Summing up the present state of our knowledge about the development of quantitative navigation in the eastern seas, we have to start with the introduction of the mariner's compass on Chinese ships some time before +1050, possibly as early as +850... Before +1300 there is hardly any evidence for the taking of star altitudes at sea by instrument, whether among Arabic or Indian pilots, and only very little for the Chinese navigators... we may not be far off the truth if we say that when Ibn Majid met Vasco da Gama at Malindi, fully quantitative navigation was some two or three centuries old 'East of Suez' ...», J. Needham, *Science & Civilisation in China* Vol. IV, Part 3 (Cambridge, 1971) 576.]

To do this successfully required the use of memorised «Rules» to ensure that the pilot always observed a chosen star consistently. The easiest such Rule for a pilot to remember would be one which used the 'man in the sky clock' and gave 'heights' in whole degrees (to the nearest whole degree) of the Pole at predetermined points on their circle around the Pole star as seen from his main port of departure, Lisbon; for example, its 'height' at the 'Head', or 'Feet', or at the ends of the outstretched arms of the 'man in the sky'.

This is illustrated, but only by implication as the figure of the man is omitted, in a woodcut enumerating, in numerals printed outside the rim of a twelve rayed 'wheel' (long customarily used to delineate months in the star clock), the height of the Pole star at Lisbon at the four most easily determined positions of the Guards — when they were at the 'Head', 'Feet' and each 'Arm':

«36.»
«Cabeca.»

«40. Braco.» «Braco. 73. [37.]»

«Pee.»
«41.»

The latitude of Lisbon is 38* 42' N. [39* assumed for the Rule] and the accompanying printed Rules say, 'Guards in the head, North star 3* under the Pole, Guards in the feet, Star 3* above the Pole', which, as Professor Taylor first perceived, was the altitude navigation rule that Columbus seems to have memorised and used in 1498 on his third voyage across the Atlantic (76).

Professor Taylor cleverly demonstrated that Columbus, by his altitude observation of 5* with 'Guards in the Head' in July 1498 satisfied himself correctly that he was in his intended 'height', which was that of Sierra Leone.

By then latitude tables had been compiled and the latitude of Sierra Leone was given as 8* N.. So, with the 'Guards in the Head', that is, when the Pole star was 3* below the Pole, 3* added to his *altitude* observation of 5* made it into an observation of 8* of *latitude*.

At some time, probably before the 1450s the pilot was also taught to use the 'height' Rules to check his distance 'made good' North or South towards his destination from his point of departure (Lisbon) by multiplying the difference in degrees between two successive observations (and of the Sun at noon) by the number of leagues in a degree. Probably in the 1470s, as the Equator was reached, he was taught how to find his latitude as distinct from his 'altitude' ('height') from observations of the Sun.

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(76) [E. G. R. Taylor, *op. cit.*, 48, where she quotes these two printed Rules from the *Addendum* to Valentim Fernandes' 1563 *Reportorio dos Tempos* from whose 12-rayed «wheel» diagram the diagram here is constructed; this (1563) diagram is reproduced as Fig. 96 in L. M. de Albuquerque, *op. cit.*, in A. Cortesão, *op. cit.*, Vol. II, 241. Fernandez' diagram dates from the xvth c..]

Before I review that very briefly I would like to explain why I have given so much attention to 'altitude' navigation.

This is because as a seaman I know that this method, which Professor Albuquerque has called «navigation by equal altitudes» was the great break-through in oceanic voyaging. However, it had already occurred centuries earlier in the Orient, in the ocean East of Arabia, most probably by Arabian pilots, but how soon after Islam burst its bounds in the VIIth century and reached the Pacific coast of China by sea is as yet unclear.

But altitude navigation was developed independently in Eastern seas much earlier than in Europe, first probably in the Indian ocean in order to exploit the wealth of the surrounding lands. It was immensely profitable commercially; it was the art upon which the whole of the civilised Orient depended long before the Portuguese entered the Indian ocean, not merely for the fruits of the Spice Islands but for the exchange of the bulk of the multitudinous products and manufactures produced in the immense territories encircling the Northern shores of the Indian ocean from East Africa to the East Indies, which made the Orient civilised and carried West from the Levant even in relatively small quantities, enriched Venice and Genoa, civilised Europe, the fruits of an older 'altitude' navigation than the West's.

The development of altitude navigation by the Portuguese into 'latitude navigation' made oceanic voyaging by the nations of the West, we Europeans, *commercially practicable worldwide,* so that we soon enjoyed not only the products of the Orient on an unparalleled scale but also those of an entirely new world, the Americas.

Altitude navigation was perhaps the greatest technological and intellectual break-through of the Renaissance because all astronomical navigation, oceanic navigation, the navigation which, during the Renaissance, opened up to Europeans the hitherto unknown islands and shores of the oceans of the world, derives from altitude navigation. It was indeed «the key to the seven seas of the world.»

I therefore feel strongly that the Portuguese, in particular the Infante, should receive more credit than in recent times he has for having been perspicacious enough to see that, *using existing astronomical knowledge and instruments,* it was possible to make economic use of islands discovered in the ocean sea, which he promptly did, as well as to find the source of European gold by exploring the West African coast by sea. And his Portuguese successors should receive due credit for conceiving the seaway to the Indies themselves and bringing it into fruition by the development of latitude navigation.

Admiral Teixeira da Mota understood the origin of altitude navigation in time-telling by the Guards, its early development in the XVth century, and its importance to civilization, though he made only passing reference to it in his important study of the evolution of nautical science and Portuguese hydrography in the XVth and XVIth centuries. There he referred to it as 'navigation by differences of altitude', 'a genuine Portuguese invention *(criação)*, a 'method much (mais) older' than what is known as «The Regiment (Rule) of the North Star» (77).

Professor Albuquerque has cautiously concluded in his study of the two oldest printed Portuguese navigation manuals that the Rule of the North Star «must have been adopted between 1455 and 1475» (78).

I, no astronomer, am going to be less prudent and maintain, as I have already reasoned, that the Portuguese had evolved 'altitude' navigation by the time that the Azores were rediscovered in 1427, if not earlier when the Madeiras lying 300' out in the Atlantic from the mainland were re-discovered in 1420 (at the latest). I base this on seamanship as well as the scholarship of my academic peers as, after I had come to this conclusion, I have established did Admiral Gago Coutinho who was of the same opinion (79).

I also base it on human nature, the reluctance of volountary colonists to be marooned on inaccessible uninhabited islands a thousand and more miles distant from their homelands.

If I read Professor Taylor aright, she was of the same mind for she wrote in *The Haven-Finding Art*, that instrumental observation of 'altura' «had been devised» by the time Cape Bojador had been rounded (1434). But she also implies that colonisation of the Atlantic islands and the ensuing trade with them could not have been carried out successfully and profitably, — as it was from 1420 — for some thirty years by 'hit or miss' navigation in the ocean. It would have been, in one word, impracticable, though she did not spell out specifically 'how' 'altura' was measured.

When sailing East or West by magnetic compass only by checking that he was keeping in the same 'height' could the pilot rectify the effect of ocean currents on his track in a North-South direction; similarly, on North-South courses his 'height' provided the only check on his progress in these directions. However, there was another source of error which I have not hitherto mentioned, magnetic variation. This phenomenon was unknown until the middle of the xvth century and, when it was known, the importance of measuring it at sea was not appreciated until the close of the century. Indeed, neither instruments nor methods to measure variation and to correct its effect were devised for use at sea until the early xvith century. Even then, frequently, far into the xviiith century pilots failed to measure and to correct for variation.

The effect of magnetic variation is to deflect the compass needle either East or West of the direction of true North so that it points to magnetic North. The amount of the deflection varies geographically and periodically, so that it is different in different places and at different periods — there is a small annual (secular) change, and geographically it can vary from zero progressively upwards to as much as 60* near the magnetic pole. In the late xvth century it was probably zero near the Azores, increasing to 22* 1/2 West off Newfoundland. So a pilot steering as he thought West when his compass was subject to 11* W. variation would be steering W. by S., and on a compass course of North he would actually be steering 11* W. of North!

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(77) [A. Teixeira da Mota, *A evolução da ciencia náutica durante os Séculos XV-XVI na cartografia Portuguesa da época* (Lisboa, 1961) 16.]

(78) [L. M. Albuquerque, *Os Guias de Munique e Évora* (Lisboa, 1965) 3.]

(79) [G. Coutinho, *A Náutica dos Descobrimentos* 2 Vols. (Lisboa, 1951-52) Vol. I, 163-95, «A escola do mar largo Atlantico e Costa de África» & Fig. opp. 184; «Cabo Bojador. A volta do mar de baga ou do Sargaço», 195-226.]

Combine this unknown cause of steering error with that of unknown ocean currents and it needs little imagination to account for the difficulty of finding islands in the ocean in the xivth and xvth centuries nor to appreciate the imperative need for a check by instrumental measurement upon progress in at least one direction. Even so, when it was provided in the form of 'altura' and, later, latitude navigation it was not an infallible means of finding an island in the ocean, even one like Madeira relatively close to the mainland — some 300 miles to the West. For example, in the xviith century, «Metius raconte qu'un exellent Pilote est party d'Amsterdam pour aller à l'isle de Madere & a fait deux fois le voyage en vain, & retourné sans pouvoir jamais rencontrer cette isle, non pour autre cause que parce qu'il ignoroit le mouuement de cette Mer laquelle insensiblement, & s'en qu'il pût s'en appercouoir luy faisoit changer de route.» (80)

As, because of the apparent rotation of the heavens there was absolutely no practical means of using the Sun, Moon or stars to measure instrumentally distance sailed East of West the best that could be hoped for was to use the apparently-fixed-in-direction axis of the heavens to measure the change in its altitude above the Northern horizon as a measure of distance sailed North or South.

There is a very clear indication that by 1455 it was usual to use the 'height' of the Pole star above the horizon to fix a ship's position approximately in a North-South direction, which is endorsed seven years later, in 1462. In July 1455 (or 1456) Ca'da Mosto said Polaris appeared «sopra il mare l'alteza di una lancia» and in 1462 that it was «levantado sopre el horizonte más de una lanca...»; another record he gave reads: «in questa isoletta appar la transmontana di alteza d'un uomo sopra il mare.» (81).

There has been a great deal written about the significance of these terms «lancia», «lanca» and «uomo» but this was cleared up definitively at the Ist of our Reunions in the discussion which followed the delivery of the paper from which I have quoted — which is an illustration of their value. For Professor Beaujouan pointed out that «La lance (rumh) et la stature d'un homme (Ramat al-insan) apparaissent en effet, dès le x^{e} siècle, dans le catalogue d'étoiles d'Abd Rahman al-Sufi, pour mesurer des angles.» (82)

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(80) [P. G. Fournier, *Hydrographie* 2^{e} ed. (Paris, 1667) 554.]

(81) [R. Laguarda Trias, *Interpretación de los vestigios del uso de um método de navegación preastronómica en el Atlantico* (Coimbra, 1970) 18, 22.]

(82) [*Ibid.*, 29.]

Ca'da Mosto was a merchant, not a pilot, it does not follow, therefore, that he used a pilot's terminology to define 'height', the indisputable fact is that he wrote of 'height' as a definition of position and in a manner which makes it clear that to do so was customary and would be generally understood. It is reasonable, therefore, to conclude that the 'custom' would have been understood in the 1420s and not unreasonable to conclude also that to take the 'height' of a place by one means or another was by then a customary practice of pilots. While not accurate by present day standards it should have been accurate enough for an experienced pilot to get within range of indications of the proximity of an oceanic island — to within bird, cloud, sea and swell indications of its proximity (or of a mainland landfall), say sixty miles off. But, as has been exemplified, this was not necessarily so, which is corroborative proof of the impracticability of making deliberately sought for island landfalls in the ocean, particularly on such remote islands as those the Azores, without any such aid.

This is endorsed by the recorded fact that «Zurara's *Chronica de Guiné* mentions, *though only in passing,* [my italics] the custom of sailing by the open sea, not only from Guinea to Portugal but from Portugal to Guinea in the early xvth century: in 1440 an expedition led by Dinis Dias sailed to the land of the Blacks without striking sail.» (83).

Zurara evidently thought it hardly necessary to mention that they sailed «by the open sea» to Guinea and unnecessary to explain how they knew when they had to make their landfall after a voyage of some 2,000 miles to the Southward out of sight of land while a current had been sweeping them along, though they did not know it *if they could not measure their progress Southwards over the ocean bed,* each day 12 miles South of their reckoning.

Even if they made good on average 5 knots (which is faster than the average) and so sailed 120 miles each day they would have been in the current for 17 days, would have been carried South of their estimated position by some 200 miles. Consequently, on making a landfall, and on finding that they were far to the South of their intended one, they would have to make a long and labourious beat out into the ocean to gain the necessary Northing, when the same problem of when or where to turn to the East once again in order to make the desired Guinea landfall would have had to be faced — and a decision taken.

Certainly men skilled in knowledge of 'routes by the stars and the Pole' did go to sea in Portuguese ships in the midcentury. The fleet which took D. Leonora, sister of King Afonso V from Lisbon to Pisa to marry the Emperor, included according to one of the German ambassadors, «capitaes» peritissimos no mar ... por mestres astrólogos bem conhecidores das derrotas pelas *estrêlas* e o pólo» as Fontoura da Costa has rendered «*...et magistris astrologis, juxta stellas et polum viarum bene doctis*».» (84)

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(83) [L. M. Albuquerque, *op. cit.*, 226.]

(84) [A. Fontoura da Costa, *op. cit.*, 35.]

In view of the importance of the Princess it would have been a prudent measure to have provided the fleet with the best pilots but whether the *«magistris astrologis»* were there for astrological purposes — medical of predictive of auspicous occasions — as would also have been deemed a prudent measure in those times, or whether this is an ambassadorial description of sea captains experienced in 'altura' navigation I find too difficult to determine with my ignorance of medieval Latin. Some scholar may think it worth re-pursuing the matter.

However that may be, I have been brought to the next development in 'altitude' navigation which, further refined, ultimately enabled Bartholomew Dias to round the Cape of Good Hope and return to Lisbon with the good news, a spectacular feat which, I often get the impression, it is generally assumed that he would do as a matter of course.

The Rule of Leagues.

In his history of *Astronomical navigation* Professor Albuquerque has observed that there is no known reference to the practical use of the *toleta de marteloio* but that it may well have been adopted by Mediterranean navigators. Again, I shall be less judicious, less reliant upon documentary evidence, reliant upon the centuries old navigational practices of seamen.

As previously remarked, much sea practice was not and still is not recorded or, if recorded at sea, is and was not kept after a successfully completed voyage. For example, ship's logs never (certainly never customarily) record *how* a pilot actually calculated his ship's position at noon, only *where* his calculations, including those based on an observation, whether terrestrial or celestial, placed his vessel at the time recorded — customarily noon. Thus, when Richard Norwood, in *The Seamans Practice*, published in 1637, included for the first time in navigational history '*A formal and exact way of setting down and perfecting a Sea-reckoning*', which he did by reprinting «*The Journal of our Voyage intended by Gods assistance from S.I.* [*Bermuda*] *in the latitude of 32 deg. 25 min. to the Coast of England, &c.*», being a professional navigatore he omitted all the calculations performed to arrive at the various entries (laid out systemmatically in columns and lines). Nor did he allude to the use of the Traverse Table — the trigonometrical table (which he had devised) equivalent to the *toleta de marteloio* of the thirteenth to fifteenth centuries — altough it was used every day to determine the amount of Northing and Easting the ship had 'made good' and which was duly entered in the log.

To know about the Traverse Table's existence and how to use it a navigator had to have a copy of Norwood's manual of navigation, *The Seamans Practice*, in which he would find it and its use described.

Similarly, the Journal records astronomical observations for latitude but not with that instrument they were made; likewise, the variation observed daily is entered, but there is no record of the instrument used to measure the variation nor of how the observation was made.

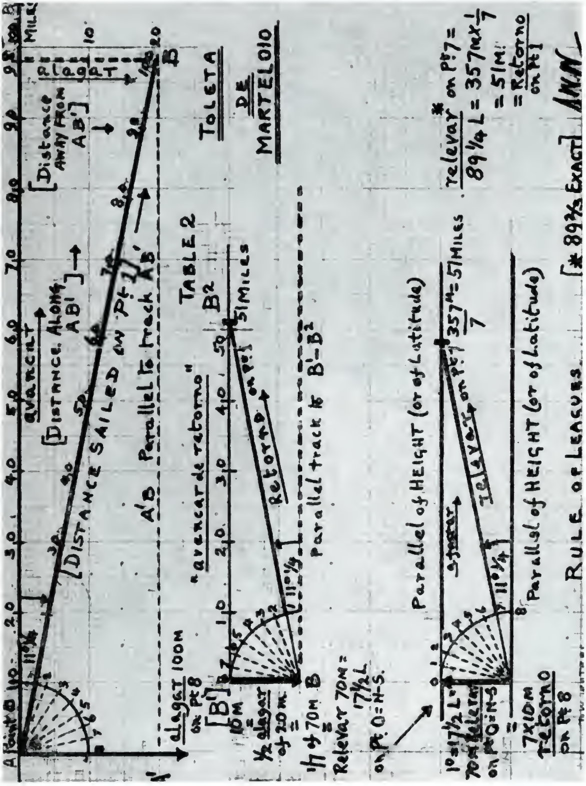

FIG. 5 — Relationship between the *Toleta de Martelolo* and the *Rule of Leagues* of the xvth century.

In the xvth century there were no formal manuals of navigation. Even if we accept that the Manual of Munich of *c.* of 1509 had a forerunner in the 1490s, it says nothing about how calculation were made. The nearest we shall ever get to written xvth century navigation manuals appear to be the five *Documentos com a Toleta* listed by Fontoura da Costa and dating between 1436 (by Andreia Bianco) and *c.* 1489 (by an anonymous Venetian) and a sixth, which Kretschmer entitled «Portolan des Gratiosus Benincasa», of 1435-1445, the latest date mentioned in the codex (85).

Both Bianco and Benincasa, it is very important to appreciate, were sea captains as well as hydrographers. Bianco signed and dated his chart of the *A*.E. Atlantic: *Andrea biancho. Venecian comito di galia mi fexe a londra M cccc.xxxxviij* and Benincasa, of Ancona, «sailed in the Mediterranean for many years.» His earliest surviving manuscript contains «his own notes about the routes betweens ports in the Mediterranean, Black Sea and, chiefly, Adriatic, with a few cosmographic rules and the working of the toleta de marteloio... It corresponds, in fact, to the xvith century «Livros de Marinharia» of the Portuguese, which often contained a rutter or portolano.» (86).

The importance of both men being sea captain lies in the fact that seamen put down in their navigation books only what is of practical use to them as pilots. Neither of them would waste time entering the *toleta de marteloio* unless they expected it to be used or to use it themselves, just as no Portuguese navigator of the xvith century filled his *Livro de Marinharia* with useless information.

Thus, at some time early in the xvth century another 'instrument' of enclosed sea navigation was modified to make it useful in oceanic navigation, the *Toleta de Marteloio*. So useful in the absence of tidal streams, it was rendered mush less so by the effects of currents of unknown velocity experienced by seamen in the ocean sea. This was because it gave them only relative courses to steer. It had two tables. The first told the pilot how far off course, how far 'outward' he had sailed from his desired course by following the course the wind obliged him to follow. The second table told him the distance he had 'made good' towards his desired direction. For example, if his desired course was (from West to) East and he had had to sail S.E. it told him (in effect) how far East he had sailed and how far 'outwards' South from his desired (from west to) East course. The second table told him how to get back from this point to his desired track.

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(85) [A. Fontoura da Costa, *op. cit.*, 356-63 (356); K. Kretschmer, *Die italienischen Portolane des Mittelalters* (Berlin, 1909; Hildesheim, 1962) 358-420, where his portolan is reprinted in full, the *toleta* and «La ragione de la luna» are on pp. 358-59; A. Cortesão, *History*, Vol. II, 181-83 & L. Albuquerque, in see also A. Cortesão. *op. cit.*, Vol. II, 434-39.

(86) [A. Cortesão. *History*, Vol. I, 181-83 (182).]

The Rule to Raise and Lay a Degree.

From these tables was evolved a «Rule to Raise or Lower a Degree». When is not clear. Professor Albuquerque thinks «it was introduced soon after the beginning of the practice of determining latitudes on board ship», that is, in the 1470s-1480s. (87).

But the Rule of Leagues, as it became known, enabled the navigator to calculate easily how far he had to sail along a given course in order to change his 'height' 'outward' from an East-West course by one degree, one degree being assumed at first to be 16 2/3 leagues of 4 Italian miles, or 66 2/3 miles. Thus it was evolved, in my opinion, as a 'Rule of Leagues' to change the '*Height*' by one degree».

According to the wind direction, which limited the course the pilot could follow, and according to the number of degrees he wished to raise or lower to get into his right 'height', a pilot could calculate easily how far he had to sail on a given course.

The archaic language of the oldest known version, in the *Guia Nautica de Munique* or Manual of Munich, of *c.* 1509 led Commandante Fontoura da Costa to place it firmly in the xvth century.

When Francisco Faleiro printed his *Tractado del Esphera y del Arte de Marear* of 1535 he included an archaic version of the Rule of Leagues, for this contained only the *relevar* course distances, also it gave them on the basis of 16 2/3 leagues to a degree, which is well known to antedate the more correct figure of 17 1/2 leagues (of 70 Portuguese miles) — introduced by the end of the xvth century (88).

The fore-going must be coupled with the fact that in the Manual of Munich the Rule begins baldly without any title:

«Item. Saberás que o grau de norte e sul é de dezassete léguas e meia: e assim hás-de saber que sessenta minutos fazem um grau.»

«Por uma quarta, releva por grau dezassete léguas e cinco sextos [sexmo] de légua.»

«E afastas da linha direita três léguas e meia.»

«Item. Por duas quartas...»

and with the fact that the Évora manual begins:

«Regimento para saberes quantas léguas entram por grau, por cada uma destas sete quartas abaixo escritas. E isto do norte e sul.»

«Primeiramente saberás que o grau do norte e sul é de xvii léguas e meia légua de Portugal, silicet, quatro milhas por légua. E LX minutos fazem um grau.»

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(87) [L. M. de Albuquerque, «Astronomical Navigation» in A. Cortesão, *op. cit.*, Vol. II, 438.]

(88) [A. Fontoura da Costa, *op. cit.*, 364 & Table XXXII, and 210-16, where the lengths of the leagues are discussed.

«Item. Por uma quarta [carta] releva por grau xvii léguas e cinco sextos [sesmos] de légua.»

«E afastarás da linha [linea] direita por grau três léguas e meia.»

«E por duas quartas...»

If this be done then it is apparent that there is good reason to consider the 'Rule of Leagues' as *a rule for raising or lowering one degree of 'height' when a pilot was practising the* earliest form of astronomical navigation, *altitude navigation.*

Nowhere in these early Rules is there any mention of 'latitude', simply of a '*grau de norte e sul*' (degree of North and of South) [Munich], and «*quantas léguas entram por grau... do norte e sul*». (how many leagues there are in a degree ...North and South [Evora], that is, in a change of 'height' of 1*.

My conclusion is that the pilot used the 'Rule of How Many Leagues there are in a Degree North and South' long before latitude ever entered into his practice. Indeed, that he used it not from the last but from the first quarter of the xvth century, with the introduction of oceanic altitude navigation.

Chronological editing of the Rules using 17 1/2 leagues to a degree reveals a succession of numerical improvements in the distances to be sailed until those by Nunes (1537), which were thereafter generally accepted. The earliest Rules appear, as is to be expected, to have been derived geometrically, and not arithmetically, and therefore are the least exact, the least exact was, of course, the original xvth century version with 16 2/3 leagues to a degree **(90)**.

How was it evolved?

I see it as a modification for use in the ocean of the enclosed sea — Mediterranean — *toleta de marteloio.* Particularly as this uses an Italian mile of 1,000 double paces of 1.48 m. (as opposed to a modern mile of 1852 m.). The result was that 16 2/3 Portuguese leagues of 66 2/3 Italian miles was about 15% short of the length of a degree of 'altitude'; the later length used, of 17 1/2 leagues of 70 Italian miles was still about 7% too short; the actual length is 111 km..

The increase suggests that the 'Rule of Leagues' was originally worked out from the existing Mediterranean *Toleta* and later modified empirically as a result of navigational experience in the ocean. This would have shown over time that 66 2/3 Portuguese leagues of 4 Italian miles were too few to raise or lower a degree of 'altitude' (91). Although 17 1/2 leagues were

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(89) [The Rules of Munich and Évora are discussed and reprinted in L. M. de Albuquerque, *Os Guias Náuticas de Munique e Évora* (Lisboa, 1965) 96-7, 138, 193-94.]

(90) [*Ibid.*, citing A. Teixeira da Mota, «Bartolomeu Dias e o valor do grau terrestre», in *Actas Cong. Int. Hist. Desc.*, II, 299-309. Lisboa, 1961; A. Fontoura da Costa, *op. cit.*, Tabela XXXII gives the comparisons, giving 17 1/2 leagues to the degree, unfortunately he omits the 16 2/3 Rule figures given by Faleiro.]

(91) [A. Fontoura da Costa, *op. cit.*, 216, Tabela XX & XXI.].

also too few it was adopted as a safe working figure because pilots preferred 'to have their reckoning before the ship' as a safeguard against unexpected stranding at night or in foul weather, on the principle, in other words, that it was better to look out for land too soon than too late to avoid disaster.

The basic problem was that in order to establish the length of a degree on the earth's surface the size of the earth had to be measured accurately and this could not be done with existing instruments. As a consequence the length of a degree was uncertain and would remain so for centuries. Pilots used the length they preferred.

While in one sense such an evolutionary origin to the 'Rule of Leagues' makes it less innovatory in another it makes rational its primitive simplistic form (in relation to the later development of latitude navigation); moreover, it conforms to the universal rule of invention 'that every invention embodies, that is, brings together and exploits, existing practices, existing knowledge, existing technology'.

The Toleta de Marteloio and the 'Rule of Leagues'. See Fig. 5.

The *toleta de marteloio* — I am describing the earliest known complete example, that of 1436 by Andreia Bianco — has two tables.

The first table gave the distance a ship sails away from the track of her desired course on each of the eight rhumbs in a quadrant of the compass and on the mathematical basis that she has sailed 100 miles along this undesired course.

Thus, if she sails away from her desired track at an angle of 11* 1/4, termed the 'first quarter' (point), this first table shows that after sailing 100 miles along this (undesired but wind-necessitated track) her distance from her desired track would be 20 miles.

This distance was termed *alagar*.

This table also gave the distance 'made good' in the desired direction (termed *avançar*) based, of course, also on the sailed distance of 100 miles in the undesired direction, but with *avançar* I am not now concerned.

So, if a ship was forced to sail 90* (8 points) away from her desired course, when she had sailed 100 miles — 100 miles away from her desired course — the table told her pilot that he had made no advance (*avançar* «0»)in his desired direction.

[First Table]

Suma

Point	Degrees	[Distance Sailed]	Alagar [Away from]	Avançar [Along]
[0]	[0]	[100]	[0]	[100]
1	11 1/4	100	20	98
8	90	100	100	0

If the pilot now wished to return to his desired track, to which he was sailing at right angles, he consulted the second table of the *Toleta.*

The second table, known as the *Avanço de Retorno,* assumed that a ship had gone away from her desired track a distance, the *Alagar* of the first table, of 10 miles which, in this example, was 1/10th of the distance he had sailed away from his desired track.

This second table gave the pilot the distance that had to be sailed along the several 8 points (quartas) of the quadrant of the compass according to the one he chose (was able) to steer in order to return to his desired track. This 'return to the desired track course' was termed *Retorno.*

Of course, on the eighth point (90* to the desired track) the *Retorno* distance would be 10 miles. Steering at an angle 11* 1/4 (on the first point) towards the desired track the *Retorno* distance would be 51 miles.

The *Avanço de Retorno* ('the distance made good in returning' table) also gave the distance made good on the return course in the direction originally, and still, desired, according to the point sailed upon. This was called the *Avanço.*

Of course, it would be 0 miles on the eighth (8) point when the ship was sailing at right angles (90*) to the desired track.

Sailing towards it at an angle of 11* 1/4 (on the first (1) point it would be 50 miles.

So a ship which had been 10 miles South of her desired track of East knew that if she sailed 8 points (90* towards it to the North she would reach it in 10 miles, but that she would make no Easting in doing so.

On the other hand, if she sailed East by North (1 point — 11* 1/4 — North of East) she would have to sail 51 miles before she got back onto her desired track.

In doing so she would make good 50 miles along her desired track, viz.:

Second Table.

Avanço de Retorno

Point	Degrees	[Return Distance]	Retorno	Avanço
1	11 1/4	10	51	50
8	90	10	10	0

To my not very mathematical mind the 'Rule of Leagues' is simply the *Avanço de Retorno* table based on a «return» distance of 16 2/3 leagues = 66 2/3 miles (later 17 1/2 leagues = 70 miles) = 1* (92).

In the Portuguese 'Rule of Leagues' the distance to sail to get back to a track 1* North or South of a ship's present track is 17 1/2 leagues on the Point «0» = North/South = 90* to a parallel of 'height'.

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(92) [A. Fontoura da Costa, *op. cit.,* Tables XXX & XXXI, p. 360 & Table XXXII, p. 364.]

In the *Toleta de Marteloio* the point to sail on to get back the shortest way any parallel track is Point «8», that is, 8 points (90*) above/below, say, an East-West track = a parallel of 'altitude'.

In the *Toleta* the distance apart of a parallel track, «*Retorno*», is assumed to be 10 miles; therefore, on point «8» (90*):

	Retorno	= 10 miles; «*Avanço*» 0 m.
on Point 1 (11* 1/4) they are:	»	= 51 miles; » 50 m.
the ratio is:		10 : 51 = 1 : 5.1
In the 'Rule of Leagues' the distances apart of the parallels is 17 1/2 leagues on point «0» (90*), therefore:		
	Relegar	= 17 1/2 leagues, *Afastar* 0 l.
on Point 7 (78* 3/4)	»	= 17 1/2 leagues, *Afastar* 0 l.
	»	89 2/3 » » 88 l.
	the ratio is	1 : 5.1.

In other words, in the «Avanço de Retorno» table of the *Toleta de Marteloio,* «Retorno» is the same as the «Relevar» of the 'Rule of Leagues'; both gave the distance to sail to get back to a parallel track.

The only difference between them was that the 'Rule of Leagues' specified parallels East-West 17 1/2 leagues apart (= *Relevar* when the course was 90* to the parallels), the *Toleta de Marteloio* parallels in any direction 10 miles apart (= *Retorno* when the course was 90* to the parallels).

As Bianco said that the pilot using the *Toleta* must know how to multiply and divide (in order to correlate his actual distances sailed with those tabulated) it was an easy step to equate the length — distance apart — of a degree of altitude — 'height' (16* 2/3 later 17 1/2 leagues) = *Relevar* with *Retorno.*

It Seems to me that these relationship must have been well known to the mathematical minded astronomers who formulated 'altitude' navigation, that the introduction of the 'Rule of the Guards' and the 'Rule of Leagues' went hand in hand, that these two new Rules were evolved at the same time, each out of long established astronomical and mathematical Rules respectively. If this be so then the 'Rule of Leagues' goes back to the first quarter of the xvth century.

The Development of Latitude Navigation.

A replacement for the Pole star became essential in the 1460s as it sank too close to the horizon to be observable and finally was lost to sight when the Equator was crossed in the early 1470s by Fernão Gomes's sea captains. A celestial body had to be usable South as well as, ideally, close to, on and North of the Equator for, with the rounding of Cape Palmas the coast was found to run Eastwards for 1,000 miles (close to latitude 5° North), where the Pole star was no longer observable to establish 'height', and then to resume its Southerly trend beyond the Equator, where 'height' from 'Lisbon' became meaningless.

The Sun offered the only practicable solution, but no longer for 'altitude' navigation based on Lisbon, for which it also had been used latterly; however, its daily change of position in the skies — its daily change of declination, its angular distance North or South of the Celestial Equator — complicated its use.

Which is where another percipient Portuguese Prince came fortuitously on the stage, the later King John II, to be entrusted from 1474 when he was aged nineteen with the development of African trade and exploration. A man of decisive personality he organised and financed the continuation of what threatened to be once again the uneconomic exploration of the sea, after the dust of the war in the Gulf of Guinea with Castille had settled at home, and to make it practicable by the development of appropriate means and methods of navigation and hydrography.

On the death of King Afonso V in August 1481 the Infante John became King John II and, when Diogo Cão returned from discovering the Congo and reaching lat. 13° 26′ S., besides honouring him in 1484 for his supposed success in reaching the end of Africa King John convened a meeting of mathematical and astronomical experts to develop a practicable form of nautical astronomy for pilots to use universally in order to establish their position in the oceans in a North-South direction.

The commissioners quickly devised a simple written annual table of solar declination and simplifed written rules to enable a pilot to determine his latitude, his angular distance North or South of the Equator, by means of an instrument handier and more robust than a quadrant, a sea astrolabe. With this he could take a noontide meridian altitude observation of the Sun at sea. By measuring the Sun's 'height' and calculating from this his latitude, the pilot was, in effect, establishing his 'height' but from a universally applicable datum line, the Equator (in fact, the term 'height' continued to be used by seamen for centuries as synonymous for 'latitude').

It was in 1484 that a Genoese hydrographer called Christopher Columbus, who had worked in Lisbon and learned 'altitude' navigation from sailing in Portuguese ships, endeavoured to persuade King John II to finance a voyage of discovery across the North Atlantic. Because of Diogo Cão's claim to have reached the Southern end of Africa by sailing down its West coast, and because of the cosmographical doubts of the King's advisers and, no doubt, Columbus's own terms which were contrary to Portuguese practice, he failed in his efforts.

The next year, 1485, the King despatched one of his navigational experts, the astronomer José Vizinho, to Guinea on a voyage to test out the practicability for seamen and the accuracy of the newly contrived method of latitude navigation thoroughly at sea and on the coast of Guinea. He did so successfully and copies of the method evolved were evidently circulated in manuscript and, by at least c. 1509, were printed in the version known as *The Manual of Munich* (93)

I have no intention of attempting to describe latitude navigation beyond saying that it is a refinement of 'altitude' navigation which makes astronomical navigation practicable universally and so the exploitation as well as the exploration of the oceans of the world practicable. Bartholomew Dias has the distinction of being the first seaman to prove this.

Hydrographic consequences of latitude navigation.

In so far as hydrography is concerned to practice latitude navigation necessitated the addition of a scale of latitude to charts. These are found on surviving charts dating from the first years of the xvith century. A diagonal latitude scale or double latitude scales showing different latitude heights on opposite sides of the chart were also introduced to reconcile positions obtained from magnetic compass courses and bearings, (which were falsified, as explained, by the effects of magnetic variation), with positions obtained from latitude observations, more nearly geographically correct (94).

The rounding of Africa, by Dias, 1487-1488.

In August 1487 Dias left Lisbon with two caravels and a store ship to achieve what Cão had failed to do. The storeship was a vital innovative addition to an exploration expedition because Cão's voyages had at least proved the virtual impossibility of getting food on the South-western coasts of Africa and demonstrated that additional provisions were essential if the crew of caravels were to survive a long voyage, a voyage of many months on end without supplies from the shore.

Moreover, Dias did not intend to call in at el Mina to top up his stores before pressing South but to by pass the Gulf of Guinea with its difficult currents and winds, by taking departure from Cape Palmas, in latitude 4* 25′ N. at the Western end of the Gulf of Guinea, and sailing S.E. directly across the Gulf to the mouth of the Congo in latitude 6* South. From there he would proceed South down the coast, as had Cão twice before him, in search of its Southern extremity and the seaway to India, which was King John's objective.

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(93) [See L. M. de Albuquerque, *op. cit.*, *Os Guias Náuticos*...].

(94) [The oldest surviving chart with a scale (in fact, two scales) is the North Atlantic and Western Mediterranean chart of *c.* 1502 in the Bayerische Staatsbibliothek, Munich, Cod. icon. 132, see A. Cortesão & A. Teixeira da Mota, *Portugalia Monumenta Cartographica*, Vol. I, 25-7, Pl. 8.; the chart of *c.* 1500 ascribed there tentatively to Pedro Reinel has since been described as anonymous by A. Cortesão in his *History of Cartography*, Vol. II, 216, Fig. 9; Mr. Tony Campbell, Superintendent of the Map Library, British Library, has informed me it is now dated post-1510.]

This shows the confidence that Dias had in the new latitude navigation for not only did it involve a change of latitude of 10* 1/2 but a voyage of 1,400 miles out of sight of land across and against currents which, by then must have been known to be powerful and variable in direction (95).

It also implies that Cão had established the latitude of the Congo on his last voyage of 1485-86 and that Dias knew it.

Following Cão's track down the coast South of the Congo Dias, still labouring against persistent head winds and the Northwards flowing Benguela Current, eventually reached a safe anchorage in what is now called Luderitz Bay, in latitude 26* 37′ S., and rested his weary crews for five days. It is here that he must have 'appreciated the situation', to use a strategic term and decided on a momentous change of tactics and strategy. Instead of continuing to beat arduously against wind and current he decided to sail on the wind and out into the Atlantic on a South-westerly course and so give his men a rest, for here, in the summer season the wind is more South-easterly than Southerly.

It is not known whether Dias had deduced the anti-clockwise circulation of the winds — and currents — in the South Atlantic but, by now, he was familar with the *Volta da Guinea*, the return track from Elmina, along which the pilots sailed first South to below the Line of the Equator to avoid battling against the Guinea Current and to pick up winds, the S.E. Trades, and a current, the South Equatorial which would bear them West and North enabling them to work their way North of the Equator on the variable winds there to pick up the N. E. Trades West of the Cape Verde, and so work their way across them Northwards to reach home by way of the Azores on a Northerly, or Westerly wind.

On the pilots' charts the *volta da Guinea* was a bold Westward sweep out into an as yet limitless ocean.

Perhaps Dias reasoned that he might well eventually find Westerlies to prevail in the higher Southern latitudes which, it was now clear, he must reach if he were ever to round Africa, just as in the higher Northern latitudes in which he had often sailed he knew Westerlies to prevail. So it proved.

Making West and, increasingly, South on a beam wind he reached, in about latitude 40* S., the belt of Westerlies that blow eternally around the Southern hemisphere and ran before them until he reckoned he had sailed farther to the East than his last point of departure. He then hauled up to the Northwards until he sighted land. Following it it trended Eastwards for some 200 miles, with a warm current flowing from the East. He had rounded Africa!

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(95) [These were initially, the Eastward flowing Guinea current with a speed of up to 45 miles per day, then the Westward flowing South Equatorial Current with a speed of up to 24 miles per day and, finally, the Northward flowing Benguela Current with a speed also of up to 24 miles a day. Inshore the Benguela Current flowed North beyond the Equator into the Gulf of Biafra, which forms the North-eastern end of the Gulf of Guinea, only dividing at the ....

By general agreement the voyage ended there — they had left their indispensable storeship at anchor off the South Angolan coast. On their return to the West they sighted and named Cape Aghulas, the Southernmost point and Cape Point which on their return the King, it is recorded, felicitously named the Cape of Good Hope. Dias evidently fixed its latitude, it is just short of 35* S.. Rejoining the storeship they sailed for home, calling on the way at Principe and, on the Guinea coast, at Rio de Resgate and el Mina whence, following the *volta da Guinea,* they reached Lisbon with their dramatic news in December, 1488.

Some three years later King John was in possession of Covilhã's report of the Western shores of the Indian Ocean.

Then, early in 1493, Christopher Columbus anchored in the Tagus claiming to have reached the Indies by sailing West across the North Atlantic from the Canary Islands so justifying, in his opinion, his belief that the world is much smaller than in reality it is.

Ensuring for the Portuguese the Eastern seaway to the Indies.

The Portuguese, from whom Columbus had gleaned such knowledge of 'altitude' navigation as he possessed — he seems never to have mastered latitude navigation — were not impressed, they concluded he had discovered some more Atlantic islands. The King, however, was sufficiently alarmed at the possible Castillian encroachment into the seas through which he planned his ships should sail to India to take steps to safeguard the Portuguese rights in them.

The two Spanish sovereigns, after Columbus's return, had promptly sought papal support for a monopoly of all lands discovered by Columbus and of navigation and settlement therein, similar to that granted to the Portuguese discoveries by the Bull *Aeterni Regis* in 1481. This gave them a monopoly West of Guinea but also South of the Canaries and so in latitudes through which Columbus wished to sail.

The first two Bulls granted the joint sovereigns' claims, the third, *Inter caetera,* «drew an imaginary boundary line from north to south a hundred leagues west of the Azores and Cape Verde Islands, and provided that the land and sea beyond the line should be reserved for Spanish exploration.»

A fourth Bull extended this Spanish monopoly Westward to «India» and so thoroughly alarmed the Portuguese.

Negotiations failing with the Pope King John II now negotiated directly with the two sovereigns. He succeeded in having the boundary line of the Bull *Inter caetera* «moved 270 leagues farther west, ...».

Parry, from whom I quote, says that the King's purpose was «to protect his African interests.»

The Treaty of Tordesillas incorporating this line of demarcation was signed in 1494. King John II had finally succeeded in excluding the Spaniards from his planned seaway to India (96).

Taking into account the Portuguese knowledge of the North Atlantic winds, the Northerly winds off Portugal, the N.N.E. winds off N. W. Africa, their experience with the *volta da Guinea* South of the Equator as well as to the West of the Cape Verde and the Azores, the latter with their Westerly winds, Dias's discovery of Westerlies in the equivalent latitudes in the south Atlantic and, finally, Vasco da Gama's bold Southerly course from the Cape Verde Islands (reached after fourteen days' sail from Lisbon) to the Equator, then his Westward and again Southerly sweep to avoid the Doldrums and to sail on the wind of the S. E. Trades in the Eastern South Atlantic until he could run before the known Westerlies to the Southern tip of Africa, all of which he did in 1497, taking all this into account I am left with a very strong impression that when King John II negotiated an extension of 270 leagues West of the line of demarcation so that it was 370 leagues West of the Azores and Cape Verde he was not so much protecting his African interests as his intended seaway to India.

The navigational importance of Dias's voyage of 1487-1488.

It has been postulated that da Gama derived his knowledge of his successfull sea route in the Atlantic to India from unrecorded Portuguese exploratory voyages sent out to establish it (97).

I do not think these would have been necessary. I think Dias's voyage was sufficient for da Gama's innovatory seaway to the Cape to have been deduced from the existing wind/sea lore of the Atlantic linked — and this is very important — to latitude navigation in the South as well as in the North Atlantic.

I say this linking factor in the South Atlantic was «very important» because in the North Atlantic the correlation between wind/sea lore must have been achieved with the introduction of 'altitude' navigation in the first or second quarters of the century, indeed, without such correlation, it would have been impracticable to use 'altitude' navigation to get a ship into the 'height' desired to find an island or other landfall without first knowing in what 'heights' favourable winds could probably be found.

Nor could such correlation have been made in the South Atlantic without the means to determine a ship's approximate latitude at sea daily (sea and sky state permitting), which only became practicable from 1485, nor without experience of the winds in the higher as well as in the lower Southern latitudes, which experience was not gained at any considerable distance from the shore until Bartholomew Dias made his South-westerly sweep into the Southern South Atlantic in 1487, nor were the winds he discovered known in Portugal until he reached Lisbon in December 1488.

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(96) [J H. Parry, *op. cit.*, 206-07.]

(97) [C. Brochado, *The Discovery of the Atlantic* (Lisboa, 1960) 84.]

When these new winds found by Dias and the latitudes in which he had found them were known, as the winds in the low latitudes and off the

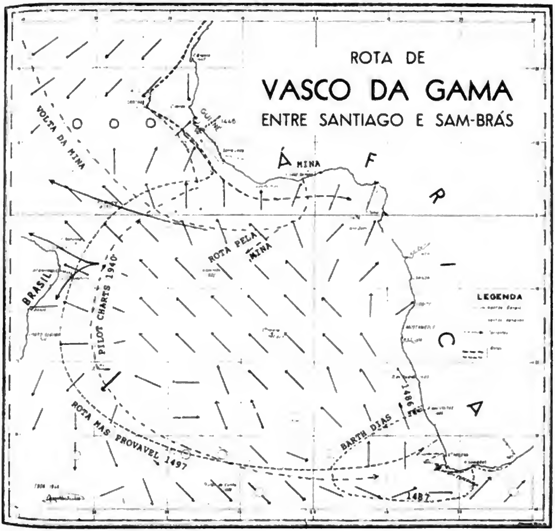

FIG. 6 — The winds of the Central and South Atlantic, Dias's and Da Gama's probable tracks to round Africa, 1487 and 1497, and the sailing ship track recommended in modern *Pilots*.

Adapted from Admiral Gago Coutinho, ed. Moura Braz, *A Nautica dos Descobrimentos* (Lisboa, 1951), Vol. I, Chart opp. p. 336.

The Admiral, who had experience in sail, made contributions of fundamental importance to elucidating the voyaging of the Portuguese pioneers in the Atlantic. On p. 336 he wrote of Cão and Dias:

«Sucessivamente se tinham descoberto os ventos do Atlântico Sul, reconhecendo-se que lá dominava um regime de ventos *provavelmente análogo* ao do Atlântico Norte — neste o aliseo de Nordeste, lá o de Sueste.»

The present writer had come to the same conclusion on the basis of seamanship and his previous studies of sea voyages, but before he had been able to study the Admiral's writings, which therefore endorse it.

Eastern shores of the South Atlantic were already known, correlation of all became practicable and as a consequence a rationally predictable wind pattern in the still unkown Western regions of the South Atlantic.

Of course, I am not suggesting that the wind system was drawn out, it would be two centuries before that was done; what I am saying again is that a great deal of seamanship is never written down, that at that time none was; that it was acquired by apprenticeship, by personal experience and observations, from explanations and speculations of master mariners passed on to young beginners in the art of seafaring. But such lore was also exchanged between pilots and master mariners by word of mouth when they met, sometimes jotted down on scraps of paper in seaport taverns. In such ways, for which only fragmentary evidence now remains, was built up a fund of knowledge common to men who sailed in particular seas, off particular coasts, in particular trades to their mutual advantage. Moreover, they kept journals in which, of necessity to know where they were, they recorded courses and distances sailed daily, wind direction and their position, of which Columbus's is a good example (98).

The extraordinarily carful preparations made to ensure the success of Vasco da Gama's follow-up voyage of 1497 to Dias's of 1487-88 and the confidence with which da Gama sailed *South-west* from off Sierra Leone, that is, at 90* to Dias's outward track of 1487 (which was also a departure from what can be called the customary one to the Congo, it will be recalled) suggest that the winds he was to use had been carefully thought out beforehand, especially by his chief pilot, but in conference with other weatherwise ocean pilots as was the custom.

Here, I suggest, in the discovery of the South Atlantic winds as much as in the discovery of the Cape lies the navigational importance of Dias's voyage of 1487-88.

It was not only a feat of superb seamanship, in the fullest sense of the word, it was also one of critical importance. This is because the discovery of the winds was critical to the exploitation of the seaway to the Cape.

The winds of the sea were the power source that drove a sailing ship through the water, they were the fuel supply of the ingenious machine, the most powerful and most complex in the Western world. He who knew the winds of the ocean seas held keys to the commerce of India and the Indies, in due course, of the world.

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(98) [J. F. Guillén, *El Primer Viaje de Cristobal Colon* (Madrid, 1943) & *La parla marina en el Diario del primer viaje de Cristóbal Colón* (Madrid, 1951).]

Preparations for and navigational and hydrographic results of Vasco da Gama's voyage of 1497-1498.

No doubt the death of King John II in 1495, the accession of his nephew King Manoel I, complicated the preparations to exploit these discoveries. But there were navigational and technical problems of ship design and of provisioning of unprecedented difficulty. With a population of one million and correspondingly limited material resources and skills in navigation, hydrography, shipbuilding and chandlery, in victualling ships for round voyages of probably two years — of unprecedented length — it is not surprising that this first merchant venture to India — for such it was — by sea was not ready to sail until July 8, 1497.

Solar declination tables to cover a 4-year cycle had been prepared to enable a return as well as an outward voyage to be made using latitude navigation, and improved astrolabes.

As for the ships these had to carry victuals for the round voyage and have cargo stowage space, to be armed against attack by the Islamic ships into whose trading preserve it was now known they would be trespassing, they had to be seaworthy against Atlantic storms, weatherly enough to sail on a beam wind and at sufficient speed to complete a passage before food and water were exhausted, and they had to be manoeuvrable and defensible. This ruled out the exlusive use of caravels. Two *naus*, the *São Gabriel* and the *São Rafael*, three-masted, high-charged ships, armed with small cannon in their upper works, were especially built. They were rigged with a square sail on the lower and top foremasts and mainmasts, a lateen on the third or mizzen mast and a spritsail set under the bowsprit for use in fair weather. The rig gave them manoeuvrability and good driving power.

It is possible that it was for such multi-decked ships that a new steering device, the whipstaff, was devised to enable the helmsman to see the foot of a sail to help him in his steering. It is known to have been in customary use in Spanish trans-Atlantic ships a few decades later.(99)

A Lagos caravel, the *Berrio*, and a store ship completed the fleet. The crews were specially picked and trained, the Captain-major's pilot was Pero d'Alenquer, who had been chief pilot to Dias.

The voyage was not only a success — though commercially it was inappropriately stored with trade goods — it gave the Portuguese navigators intimate knowledge of the stars, charts, navigational instruments and techniques used by Arab pilots to navigate their lateen rigged dhows by 'altitude' in the Indian ocean. The results are embodied in the magnificent and amazingly accurate charts of the Indian seas that within a matter of a few years Portuguese hydrographers were constructing — by 1502 the East coast of Africa had been charted close to reality. This in itself was an astonishing technical achievement, no less so than the voyage itself — from the Cape Verde to the Cape an unprecedented 4,000 miles at least, 93 days at sea, the longest time ever, the round voyage a total of 22,000 miles, almost the circumference of the earth (100). And it was to be repeated year after year henceforth thanks to latitude navigation and ocean wind lore, both pioneered by Bartholomew Dias.

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(99) [J. H. Parry, *The European Reconnaissance* (London, 1968) 353.]

Some cartographic consequences of Dias's voyage of 1487-1488.

I want, for a moment, to reflect upon some of the cartographic consequences of Dias's voyage of 1487-88 which had made that of da Gama ten years later practicable.

Perhaps not surprisingly, in view of the way in which the Portuguese African discoveries «were recorded in the charts and atlases drawn at Venice from 1467 onward by Grazioso Benincasa of Ancona, from the information of the Venetian Alvise da Cadamosto, who had made two voyages to Guinea for Prince Henry», Dias's discovery of the Cape and his coasting Eastwards beyond it were revealed to the world in a woodcut Florentine map of the world within a year of Dias's return. Very appropriately it was constructed by Henricus Martellus in Florence, the home city of the scholar Toscanelli, whom King Afonso V had consulted in 1474 on the easiest seaway to the Indias and who, born in 1397 had died only seven years before, in 1482 (101).

Apart from this and from the East coast of Asia, where a bordering sea is shewn, Martellus's map is otherwise much as depicted by Ptolemy. But the seaway to India shewn in Fra Mauro's world map of 1459 and the accompanying statement that the Indian Sea is an ocean, not a lake, were now both unequivocally confirmed by the initially hydrographically delineated discoveries of Dias, clearly depicted upon it.

In charting his discoveries Dias had changed the geographical, the cartographical face of the world dramatically.

But I have a very strong feeling that Dias had achieved even more than this, that it was a consequence of his voyage that the pictorial way of representing the earth was also changed dramatically. For, instead of being represented artificially in two dimensions on flat sheets of vellum or paper, as hitherto, the world henceforth was represented realistically also, in three dimensions, as a globe.

Instead of the appearance of the spherical earth being distorted, because it is impossible to represent realistically on a flat (plane) surface the curved

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(100) [A. Teixeira da Mota, *Méthodes de navigation et cartographie nautique dans l'océan indien avant le XVe siècle* (Lisboa, 1963). See especially Fig. 4; *A África no Planisfério Portugues Anónimo «Cantino» (1502)* (Lisboa, 1977); L. Barradas, *O sul de Moçambique no Roteiro de Sofala do piloto Ahmad Ibn-Madjid* (Lisboa, 1967); I. Khoury, trs. and ed., *As-Sufaliyya «The Poem of Sofala» by Ahmad Ibn Magid* (Lisboa, 1983).]

(101) [L. Bagrow, ed. R. A. Skelton, *op. cit.*, 105-06 & PLs. LII & LIII.]

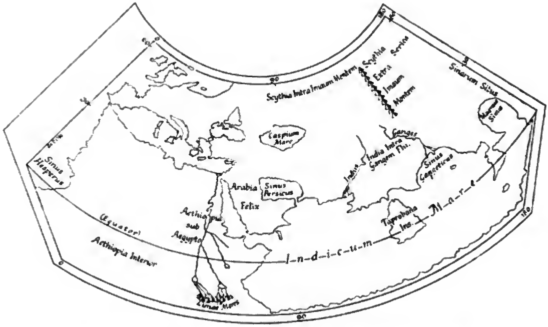

FIG. 7 — Ptolemy's world outline, from the Rome edition of 1490. From G. R. Crone, *Maps and their Makers*, 4th Edition (London, 1968) p. 46.

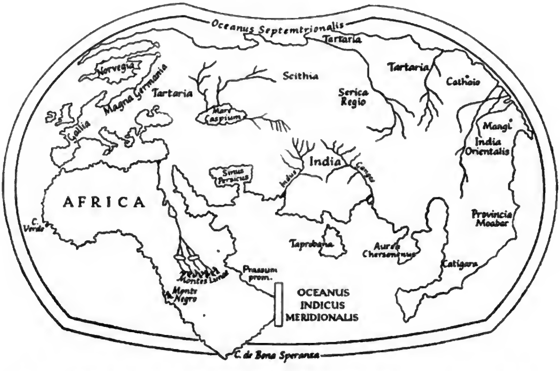

FIG. 8 — Outline of Henricus Martellus' Map, 1489, showing the dramatic change made to the face of the world by Dias's voyage of 1487-88.

From G. R. Crone, *Maps and their Makers* 5th Edition (London, 1978) p 37.

Not only is «C. de Bona Speranza» shown and «Oceanus Indicus Meridionalis» as an extension of the Atlantic ocean, but the West coast of Africa is depicted realistically. Apart from this and the extension of the South-eastern peninsula below Catigara, the outline is as depicted by Ptolemy. Nevertheless, the reality of a seaway to India by way of the Cape is manifest.

surface of the Earth, it was shown within a few years — from 1492 — also realistically spherical in form, in miniature, in the round, without the mathematical distortion of the outlines of its lands and seas necessary to represent them on a plane surface (102).

I believe that the first known terrestrial globe — Martin Behaim's — was inspired, conceived and created directly as a result of Dias's epic voyage. Creatively it was a subtle but very tangible blending of the arts of the sculptor and of the illuminator with the nascent sciences of the cosmographer and cartographer and the empirical knowledge founded on the science of nautical astronomy of Portuguese master mariners, seamen.

I emphasise the empirical contribution of the Portuguese seamen because, although indisputably they had been taught their cosmography in accordance with the doctrines of Sacrobosco, they had evidently already satisfied themselves, unlike Columbus, that of the four elements of earth, water, air and fire those of earth and water, contrary to the teachings of Sacrobosco, comprised one and the same globe. Almost a century would pass before this was accepted academically and then the proof put forward and accepted was based upon the astronomical observations of Portuguese seamen (103).

On this globe were delineated the outlines of the coasts of the world known to European, most notably because uniquely, to Portuguese seamen, together with the Ptolemaic coastlines of the rest of the known world — and a great deal more, but the coastlines were the crucial features, for they revealed the now known seaway around Africa to the Indies discovered by Dias.

So I see Martin Behaim's famous globe of 1492 as a realistic attempt to show to Nurnberg financiers, amongst the shrewdest and richest in the European world, for whom it was constructed, the pros and cons of speculating in ocean voyaging. The globe portrayed realistically the comparative risks of putting money into the Portuguese project to circumvent the Veanetian spice trade by reaching India by the seaway around Africa known, thanks to Dias, to be a reality and practicable, and of backing Columbus's scheme of doing so by sailing by what he asserted was a much shorter and therefore quicker but as yet undiscovered seaway West across the North Atlantic (104).

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(102) [«... Messer zoane Caboto... a most expert mariner.. has the description of the world in a map, and also in a solid sphere, which he has made, and shows where he has been...», Raimondo de Raimondi de Soncino to the Duke of Milan, 18 December 1497, from J. A. Williamson, ed., *The Cabot Voyages and Bristol Discovery under Henry VII* (Cambridge, 1962) 209-10.]

(103) [W. G. L. Randles, *La naissance d'un concept nouveau à l'époque des grandes découvertes maritimes: le globe terraque*, (Lisboa, 1985), Separata da *Revista da Universidade de Coimbra*, Vol. XXXIII, Ano 1985, pp. 329-338.]

(104) [Columbus probably saw only the prototype map used in the construction of the globe. A Ms. wall map by Martellus, in Yale University Library, is the only world map of the xvth century other than Behaim's globe to be graduated in longitude. Its esmate of the distance between Europe and Eastern Asia corresponds to that of Toscanelli, expressed in his 25 June 1474 letter. L. Bagrow, ed. R. A. Skelton, *op. cit.*, 72 & Pl. LV.]

Cosmographical, Economic and Strategic consequences of the Dias voyage.

Dias returning from rounding Africa I see as the forerunner heralding also to the most percipient of the European intelligentsia a change in their concept of the form of the world itself, and to far-sighted merchants and statesmen the imminent arrival of economic and strategic changes in the balance of power amongst European states. Perhaps the financiers of Nurnberg and King Henry VII of England were amongst the first to perceive the latter consequences. It was a Spanish cosmographer, Antonio de Nebrija, it appears, who first took into account the experiences of the Atlantic explorers in describing the sphericity of the earth in his *In Cosmographiae libros Introductorium*, published in Salamanca in 1498 (105).

Randles has summarised the original Aristotelian concept of the form of the earth and the medieval modifications to it which the Portuguese oceanic navigators had been taught in the 1480s as the basis of latitude navigation. It was encapsulated in Sacrobosco's *De Sphaera* printed in Venice in 1485 and 1490. Portions of this were incorporated in the earliest surviving printed Portuguese navigation manual, of *c.* 1509, a version of which is known to have been in use a decade earlier and must have been in use in the mid-1480s at the latest (106).

This includes a «Gravure représentant les sphères de la terre, de l'eau, de l'air et du feu ... La terre émerge à peine de l'eau comme une pomme qui y flotterait...» (107).

It was a woodcut of the cosmographers' concept of the form of the earth. It showed a portion of the Northern surface of a small, excentric sphere of earth emerging above the surface of a much larger sphere of water (sea). Yet, Randles has pointed out, «La condition première d'une navigation hauturière utilisant des techniques astronomiques au sud de l'équateur était que fut levé l'obstacle constitué par le modèle péripatéticien.» And he adds, «On ignore comment et dans quelles circonstances il fut surmonté.» (108)

In my view this was one of the theoretical problems that had to be put to the test of experience by José Vizinho by specific astronomical observations during his sea trials in 1485 of the 'Regimento do Astrolabio e do Quadrante' evolved by the commission of 1484. His sea trials evidently confirmed unequivocally what pilots such as Cão would seem, from their prior navigational achievements in equatorial waters, to have already demonstrated, that latitude navigation on and South of the equator was practicable.

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(105) [W. G. L. Rancles, *op. cit.*, 6/332, 4/330 & 12/338.]

(106) [A. Fontoura da Costa, *op. cit.*, 205 quotes from the *Carta de Mestre João* (1 de Maio de 1500), who was on Cabral's voyage of 1500 to India, in which he wrote «... tomáamos a altura do sol ao medio dia... segundo as regras do astrolabio...»; the title of the Manual of Munich is: *Regimento* [*regra*] *do astrolabio e do quadrante*... It must go back to 1484/85.

(107) [W. G. L. Randles, *op. cit.*, 12/338.]

(108) [*Ibid.*, 6/332.]

Vizinho evidently, in the light of subsequent navigational practice, proved also the suitability of the 'Regiment' compiled for seamen to use in low and Southern as well as Northern latitudes.

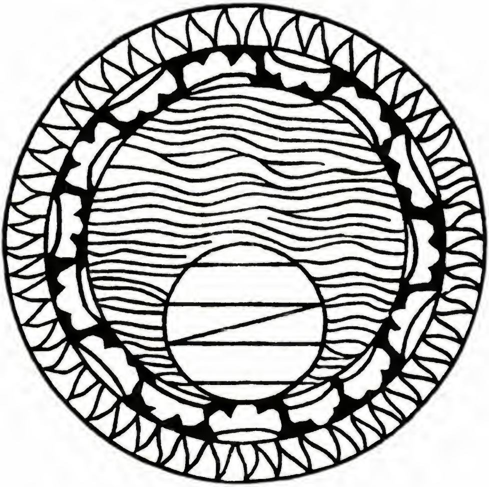

FIG. 9 — Figure representing the spheres of the earth, water, air and fire in the *De Sphaera* of Sacrobosco, Venice, 1485 and 1490.

The earth just emerges from the water like an apple floating in it.

The same woodcut appears in the editions of *De Sphaera* of Gasparino Borro, Venice, *c.* 1494, in the *De Compositione Mundi* of Paul of Venice, 1498 and in the *Tratado da Sphera*, Lisbon, *c.* 1509 and *c.* 1518, the earliest surviving Portuguese navigation manuals (See L. M. de Albuquerque, *Os Guias Náuticos de Munich e de Evora* (Lisboa, 1965) 155.

From R. W. L. Randles, *op. cit.*, 12/338.

These same trials must also have confirmed, if it had not already been established, that for 'latitude navigational *practice*' the length of a degree was 17 1/2 leagues.

The cosmographical implication was clear, at least to the Portuguese cosmographers who formulated the 'Regiment' but, as already observed it was first expressed in print by the Spanish cosmographer, Antonio de Nebrija, in 1498. «Nous devons, écrit-il, supposer, ce qui est facilement prouvé par les physiciens et les mathématiciens, que la surface de la terre et la surface de l'eau ont ensemble la forme d'une sphère, et qu'elles ont en commun le même centre que le centre du monde. Que cette surface soit sphèrique, on doit le comprendre, non par un raisonnement géométrique, mais par l'expérience des sens.» (109).

However, this being the High Renaissance Antonio de Nebrija displayed, Randles points out, what Lucien Febvre so aptly termed «l'insensibité à l'incompatible» characteristic of many intellects of that time, for he also asserted on the same page that the *orbis terrarum* known to us protrudes above the sea like an isle! But it was a beginning.

The first unequivocal definition of the terraqueous globe came, perhaps not surprisingly, from a Portuguese cosmographer, Pedro Margalho in his *Physices Compendium*, also published in Salamanca, in 1520.

«Les marins portuguais, écrit-il, avaient vérifié qu'un degré de distance angulaire sur la terre correspondait à un degré sur l'eau.» (110)

Although this was reaffirmed by Pedro Nunez in his *Tractado da Sphera* of 1537 it was not universally accepted until Christopher Clavius's third edition of his commentary on Sacrobosco's *De Sphaera*, of 1581, with its detailed arguments of the experience of «les marins... sur la mer océane» (111).

Of particular relevance to my theme is Clavius's demonstration of the sphericity of the earth in a North-South direction, because this was what concerned the Portuguese pioneers of latitude navigation. Clavius wrote: (112)

«Lorsqu'on navigue du nord vers le sud, comme, par example, du Portugal, où l'élèvation du pole est de 40*, vers les Canaries, [...] après avoir parcouru un degré entier, on constate que l'élèvation du pole n'est plus que de 39* [...]. On observe le contraire quand on navigue du sud vers le nord, par exemple [...] du Portugal vers l'Angleterre. C'est un signe évident que l'eau et la terre ont la meme surface convexe du nord au sud, de telle sort que ni la terre, ni la mer ne présente une courbe plus accentuée vers le haut, mais que l'un et l'autre élèment sont à égale distance du centre du monde...»

This was the crux of the question for the Portuguese navigation experts evolving latitude navigation in the 1480s, and Clavius's citation of the change in elevation going from Portugal to the Canaries suggests strongly how the Portuguese had settled the question of the length of a degree in the xvth century.

Indeed, Cão's voyage of 1482, during which he discovered the Congo and reached latitude 13* 26′ S. suggests that they had by then already satisfied themselves on this point and that latitude navigation was practicable South of the equator.

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(109) [*Ibid.*, 6/332-7/333.]

(110) [*Ibid.*, 7/333.]

(111) [*Ibid.*, 8-9/334-35.]

(112) [*Ibid.*, 9/335.]

Whatever the doubts of cosmographers about the shape of the world it is again evident from their navigation that, by the 1480s, Portuguese seamen had none.

Although the first reference to the use of globes by Portuguese pilots is the *mandato real* of 13 November 1504, there is good reason to suppose from its wording that, like John Cabot, they were making and using them in the 1490s (113).

The advent of the terrestrial globe is another demonstration of nautical practice outstripping cosmographical theory, of the influence of man's encounter with the sea upon scientific thought and practice in the Renaissance and, of course, upon financial investment. Consider also the heavens.

Bartholomew Dias, a sea captain skilled in nautical science, was the first European to see many of the stars of the Southern hemisphere for the first time. So his voyage was to have profound effects upon the science of astronomy also. I observe this because the influence of nautical astronomy upon scientific thought and practice in the Renaissance is, to the best of my belief, a field ripe to be harvested by historical research.

Turning now to the economic effects of Dias's voyage it is to be remarked that, if Portugal was the first to feel these beneficially, Venice was the first to feel them adversely. Considering the immense wealth that Venice drew from the spice trade originating in the Indian peninsula and the East Indies this is not surprising. What is surprising is how slow the Venetians were to recognise the inherent threat to their dominant position in the European scene.

After da Gama's return the European merchants flocked to Lisbon for, although he brought back few spices, there had been a dearth of them throughout the Mediterranean for five years, the effect of wars. This benefitted the Portuguese who, grasping time by the forelock, hastily fitted out a fleet of thirteen ships for the Indies. It sailed in 1500 under the command of Pero Alvares Cabral. Although only four returned, in 1501, they did so with holds full of spices. It was only then that the Venetians awoke to the threat to their supplies of spices.

But already the Portuguese had found that they had to pay cash for the spices bought in India. In order to ensure getting the copper and silver needed they decided to send cargoes of spices directly North in their own spice ships so that they would be marketed nearer the mines in Germany from which the metals came. Thus the first Portuguese spice ships reached Antwerp, the chosen port, in that same year of 1501.

It was the first sign of a new order initiated by the success of the Dias voyage, of the alteration at the end of the fifteenth century of world trade routes and the beginnings of an Atlantic economy. These changes decided that Antwerp was to become a «world capital», that the economic centre of Europe, with all that that implies, was to move North of the Alps to the Netherlands.

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(113) [A. Fontoura da Costa, *op. cit.*, 209.]

Three years later, «in 1504, when the Venetian galleys arrived in Alexandria in Egypt, they found not a single sack of pepper waiting for them.» (114)

In 1508 the Portuguese king founded the *Feitoria de Flandres*, the Antwerp branch of the *Casa da India* in Lisbon. Fernand Braudel points out that this was because «the major market for pepper and spices was northern and central Europe a market hitherto supplied from the south, via the *Fondaco dei Tedeschi* in Venice. Because, too, Portugal had maintained ancient shipping links with Flanders. But last and most important of all, Portugal had ... neither the resourses nor credit with which Venice had ... organised the distribution of spices from start to finish.» So they «entrusted their business to the market place of Antwerp...» with the result that, «Within a few years the Venetian monopoly had been broken or at any rate severely dented.» (115)

Antwerp's rise to supremacy was assured. It continued, despite the close of the *Feitoria de India* in 1539, because the Spanish silver from South America was by then flowing into the city from Seville, the Low Countries being by the Spanish, and Antwerp the financial centre of the German «merchant-moneylenders... who raised and transported the money without which there would have been no imperial policy...»; the policy, that is, of the Emperor Charles V, master not only of Spain and the Netherlands, the empire and Italy, but of all the Spanish lands in the Americas and of the silver, that soon flooded into Seville from the mines of Potosi, carried thither in the annual *flota*. Moreover, by then «the ships of Zeeland and Holland had taken over the Flanders-Spain run, ... finding the way clear since the Biscay ships had been attracted away to the *Carrera de Indias*, leaving a gap to be filled in the shipping between Bilbao and Antwerp...» (116).

It is true that by then Venice had recovered about half the spice — the pepper — trade. Despite gaining control by 1511 of the Indian ocean's key points — Kilwa, Mombasa, Ormuz, Goa and Malacca — the Portuguese had not been able to control the country ships of the Arabian, Persian, Gujerati and Malayan merchants, they were too numerous, too elusive for the forces the portuguese could deploy against them and the Red Sea route to Egypt, past Aden which they had failed to capture, remained open.

Nevertheless, by 1501 the focus of European trade, of European world trade had already shifted — maybe imperceptibly to most observers in the first few years — but inexorably from Venice to Antwerp. Antwerp was now 'the world's capital'. The axis was now Antwerp-Malacca, and by way of the Cape as well as of the Levant.

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[114] [F. Braudel, *op. cit.*, 143.]

(115) [*Ibid.*, 149.]

[116] [*Ibid.*, 151; the Potosi mines were opened in 1545.]

Consider now the strategic effects of the Dias voyage. These are the inevitable consequences of the shift of the European economic centre to Northern seas. To reach Antwerp every ship sailing into or from the ocean had to pass through the well-named Sleeve, the English Channel, dominated to the North by England, around the coasts of which island also any ship wishing to avoid the passage of the Sleeve had to sail. From being on the Northwestern rim of European civilisation England was, with only twenty miles of sea between, now close to the very hub of the commerce of the Western world.

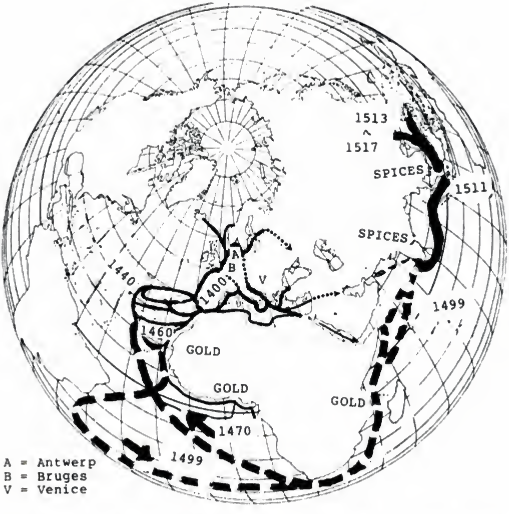

FIG. 10 — The Expansion of Europe — A Century of Portuguese Maritime Enterprise, 1400-1499. Malacca was captured in 1511, the Spice Islands reached in 1513, China in 1517.

But even closer was Holland, with its continental port of Amsterdam and its coastline flanking the Eastern approaches to the port of Antwerp on the Schelde and of the Sleeve beyond.

When the Protestant Reformation broke upon the European world in 1517 the position of the Low Countries and England became doubly important strategically. When the wars of the Reformation climaxed in the capture of Antwerp by the Catholic forces of Spain in 1585 and the blow was countered by the blockade of the river Schelde by the Protestants of the seven Northern United Provinces and of England the future of Europe depended upon who commanded the Sleeve. If Antwerp continued cut off from the sea Amsterdam, as capital of Holland, the dominant Province of the seven, was singularly well suited to take over her European role of 'a word capital'.

Amsterdam was also singularly well situed. Less than a hundred miles to the North of Antwerp the great port lay, like the rest of its Province unassailable behind impassable dykes, flanked by the North and Zuider seas, the continental focus now of all the Northern seaways, with waterways penetrating far inland; and it was served by innumerable ships of every variety of rig and build appropriate to the goods they carried and the seas and waterways they sailed.

And the time was right. Within three years of the Catholic capture and the start of the Protestant blockade of Antwerp the issue was settled — by the defeat by the English fleet in 1588 of the Armada of Spain in its attempt to gain control of the Sleeve. With that decisive Protestant naval victory Amsterdam became, overnight, 'the world capital' of Europe.

The Rise of the Dutch Republic, like that of Venice, a society begotten by the sea, was thus in the direct line of the results of the rounding of the Cape of Good Hope a century before by the Portuguese sea captain Bartolomew Dias.

English seamen having mastered in the 1550s with Spanish tuition the art of oceanic navigation developed by the Portuguese, took up the manufacture of instruments of navigation. In 1581 the scientific discovery of magnetic dip by Robert Norman in the course of methodical experiments with a sea compass needle initiated the Scientific Revolution in England (117).

Of such is the importance of the history of the sea in the history of man.

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(117) [R. Norman, *The New Attractive* (London, 1581).]

Epilogue.

I have no false sentiment about the sea. It is cruel, deceptive, violent, remorseless, unforgiving of the least weakness, incompetence or carelessness, and unappeasably insatiable when it comes to swallowing up the unwary or the weary who voyage upon it.

This is as true to-day as it was in Dias's day.

For Bartholomew Dias made a second voyage towards India. He was in Cabral's fleet which, after sailing from Lisbon in March, 1500, discovering and taking departure from Brazil for the Cape, was caught in a sudden squall. Dias was in one of the four ships which capsized. No attempt was made at rescue, probably none could be.

The four ships sank with all hands.

«Toll for the brave —
The brave that are no more:
All sunk beneath the wave, ...» (118)

Moreover, as if such dangers were not enough, in Dias's day long voyages at sea deprived men of the fresh fruits of the earth so much that they fell ill with that terrible deficiency disease, scurvy, and most afflicted died.

From the time of the first non-stop voyages across the South Atlantic to and from the Cape of Good Hope, da Gama's of 1497 and 1498, scurvy was to be the sourge of oceanic seamen, and would be so into the XIXth century.

On da Gama's voyage half — from 80 to 100 hundred of the total of about 170 men forming his crews, died (119).

Which makes all the more remarkable the courage of the long distance ocean seamen who followed in his tracks.

Like Miranda in William Shakespeare's *The Tempest* one is forced to exclaim, for all their toughness:

«How beauteous mankind is! O brave new world,
That has such people in't! (120)

Now, «These our actors», who «were all spirits» once,
«Are melted into air, into thin air...»
for
«...We are such stuff
As dreams are made on, and our little life
Is rounded with a sleep.» (121)

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(118) [W. Cowper, *On the loss of the Royal George*.]

(119) [G. R. Crone, *The Discovery of the East*, 27, 38.]

(120) [Act V, i, 182.]

(121) [*Ibid.* IV, i 148.]

And we can say with another poet familiar with the sea, Edmund Spenser:

> «Sleepe after toile, porte after stormie seas,
> Ease after warre, death after life, does greatly please.» (122)

So, now, my tribute to the immortal memory of Bartholomew Dias, Master Mariner, being ended, in Shakespeare's words (123),

> «deeper than did ever plummet sound
> I'll drown my book.»

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(122) [*The Faerie Queene*, I. IX, 40]

(123) [W. Shakespeare, *The Tempest*, v. i. 56.]